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HANDBOOK

OF

NATURAL PHILOSOPHY,

FOR

SCHOOL AND HOME USE.

BY

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WOOLWORTH, AINSWORTH, & CO.

117, WASHINGTON STREET, BOSTON;

111, STATE STREET, CHICAGO.

1869.

By the same Authors,

HANDBOOK OF CHEMISTRY.

HANDBOOK OF THE STARS.

These are elementary manuals of Chemistry and Astronomy, on the same plan this book. In each of the three, the more difficult and theoretical portions of the subject are treated in the Appendix.

Also,

THE CAMBRIDGE COURSE OF PHYSIC

IN THREE VOLUMES:

I. CHEMISTRY.
II. NATURAL PHILOSOPHY.
III. ASTRONOMY.

CAMBRIDGE:
PRESS OF JOHN WILSON AND SON.

PREFACE.

THE great favor with which the *Natural Philosophy* of the *Cambridge Physics* has been received has encouraged the authors to comply with the urgent demand for a brief and elementary text-book on the same subject. It is impossible to prepare a book which shall be adapted to all schools; but it is hoped that the plan of this manual is such that it may meet the wants of quite a wide range of schools. In the body of the book, little is attempted beyond a clear and brief statement and illustration of those facts in Physics which are of special importance on account of their practical or theoretical bearing. It is hoped that this part may furnish all that is needed for the higher classes in Grammar Schools. This is followed by an *Appendix*, which contains chapters on the physics of the atmosphere, on the theory of molecular motions, and on the origin and transformation of energy. This part is intended to fit the book for the use of those High Schools which have not time for a larger work. There is no overlapping of subjects; but the Appendix is a more difficult chapter which naturally follows.

The material of the book is drawn in the main from the sources enumerated in the Preface of the larger *Natural Philosophy*.

We have not forgotten the great advance recently made in the practical applications of the physical forces,

as well as in the theories of the science. In the body of the book, we have given the preference to facts which are of practical interest. It is for this reason that frictional electricity occupies so little space compared with current electricity. A few years ago, frictional electricity held the first place in the school books; but in practical importance it has dwindled into insignificance, while voltaic and magnetic electricity have become of immense value in the arts. Electricity now means something more than toy experiments with attractions and repulsions, and the explosion of gunpowder and gaseous mixtures.

If the teacher thinks that we have varied somewhat from our rule in bringing the double refraction and polarization of light into the body of the book, he can omit those sections.

The chapter on Machines is certainly not too full for boys; and it is very easy to abridge it for classes of girls.

The Appendix also contains problems and notes which give a full account of the apparatus needed for the book, and directions for performing difficult experiments. For numerous illustrations which the teacher can use in oral instruction, we would refer him to our larger *Natural Philosophy*. These could not be added here without making the book too bulky; and it is our conviction that such illustrations come from the teacher's lips with a force which no written statement can give them.

CAMBRIDGE, February 15, 1869.

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HANDBOOK

OF

NATURAL PHILOSOPHY.

COHESION.

ter is made up of Molecules. — When a piece heated to a temperature of 32°, it melts and be- ater. The particles of the ice hold together it in melting they have been loosened so that e among themselves with the greatest ease.

:r be heated to a temperature of 212°, it boils mes steam. Its particles are still farther sepa- n one another.

articles of which all bodies are built up, and e loosened and separated when a solid melts uid boils, are called *molecules.* Molecule is a n the Latin, and means *a little mass.*

ecules are exceedingly small. — It is impossible solid so fine as to convert it into a liquid. A gold may be divided into particles so small, that barely be made out with a powerful microscope, old is solid still. When heated, however, the d gold becomes a liquid; that is, each minute separated into molecules. These molecules, much too small to be seen with the best micro-

Molecules are not in actual con- a brass ball, which at the ordi- perature will just pass through a ure 1), be plunged into a freezing and left until it becomes very cold, en pass through the ring very eas- uching it at all.

Fig. 1.

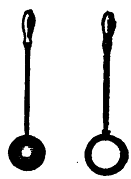


Fig. 2.

If a bulb with a projecting tube be filled with water up to a certain point on the tube, and the bulb be then plunged into a freezing mixture (Figure 2), the water will fall in the tube.

If a similar bulb be filled with air, and the end of the tube be held under water (Figure 3), and the bulb be cooled by means of a freezing mixture, the water at once rises in the tube; showing that the air occupies less space when cooled.

Fig. 3.

We find, then, that solids, liquids, and gases contract when cooled; and there seems to be no limit to this contraction, for they continue to contract, however much they are cooled.

Now this contraction is best explained by supposing that the molecules come nearer together; and since, so far as we know, a body may continue to contract indefinitely, it follows that the molecules are never in actual contact.

4. *The Spaces between the Molecules are immense in comparison with the Size of the Molecules.*— Though the spaces between the molecules are very minute, since they cannot be discerned even with the most powerful microscope, there are good reasons for believing that they are immense in comparison with the bulk of the molecules themselves.*

* The molecules of a body may be compared to the earth, sun, moon, and stars, and the spaces between the molecules to the spaces between these heavenly bodies. If we imagine a being small enough to live on one of the molecules in the centre of a stone, as we live on the earth, he would, on looking out into the

An Attractive Force and a Repulsive Force act en Molecules. — If we attempt to pull any solid er, we perceive at once that the particles of it is composed are held together more or less . That which holds them together is called an *ctive force.* If a glass rod be dipped into water, a hangs from its end when taken out. This drop is up of molecules which are evidently held together. e case of liquids, the molecules are held together ebly, and the attractive force seems to be slight.

rubber bag partially filled with air, and closed so be air-tight, be placed under the receiver of an air-, and the air exhausted from the receiver, the air the bag will at once expand, as we see by the out of the bag. This shows that gases when left mselves expand; that is, their molecules separate. e force which separates the molecules is called a *sive force.*

ce these forces act between molecules, they are *molecular forces.*

These two Forces act together. — A brass ball (see e 1) which will just pass through a ring at the ordi- temperature, will not pass through the ring after heated; showing that the molecules of the ball been pushed apart. If, however, while the solid is g, we attempt to pull it asunder, it resists; show- at the molecules are still held together by an attrac- orce. It is evident, then, that both forces act er.

bout him, see here and there, at immense distances, other les, as we see the scattered stars in the heavens at night. olecules, though exceedingly minute, are perfectly distinct efinite masses, like the earth, moon, and stars; and they parated by spaces many thousand times as great as that ed by each molecule.

7. *The Three States of Matter.* — When the attractive force is considerably stronger than the repulsive force, matter is in *the solid state;* when the two forces are nearly balanced, it is in *the liquid state;* and when the repulsive force is the stronger, in *the gaseous state.*

8. *Cohesion and Adhesion.* — The force which holds the molecules of a solid or liquid together is evidently the *excess* of the attractive over the repulsive force; for if the two forces were just equal, they would just neutralize each other, and the molecules would not be held together in the least.

In the case of iron or water, molecules of *the same kind* are held together. When we mark on a blackboard with a piece of chalk, or write on paper with ink, molecules of *different* kinds are held together.

The force which holds together molecules of the same kind is called *cohesion;* that which *holds together molecules of different kinds* is called *adhesion.*

9. *These Forces act only through insensible Distances.* — Two pieces of lead will not cohere if their surfaces are rough; but if we make them perfectly smooth and clean, and press them firmly together, they cohere quite strongly. Plates of glass, from simply resting upon one another in the warehouse, have been known to cohere so firmly that they would break elsewhere as readily as where they came in contact.

10. *Solids have considerable Cohesion.* — Matter, as we have seen, exists in three states, the *solid*, the *liquid*, and the *gaseous*. The distinguishing characteristic of *solids* is that the attractive considerably exceeds the repulsive force. In solids, therefore, the cohesion is always considerable. The various properties of solids result from modifications of this molecular force.

11. *Tenacity.* — We find on trial that it is much easier to pull in two a rod of lead than a rod of steel of the

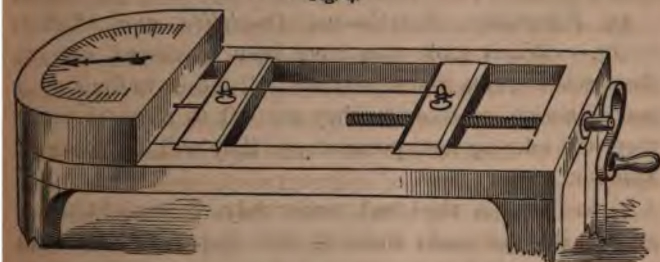
same thickness; showing that the molecules of some solids cohere more strongly than those of others.

When a solid is thus pulled in two, it is said to be *ruptured*. *The power which a solid has of resisting rupture* is called *tenacity*.

The relative tenacity of different solids is determined by finding how much force is required to rupture rods of the same thickness made of them. If it takes twice as much force to pull asunder one rod as another, the first solid is said to have twice the tenacity of the second.

The relative tenacity of solids may be found by means of a machine called a *dynamometer*. This name is made up of two Greek words, and means *force-measurer*.

Fig. 4.



One form of the machine is shown in Figure 4. It consists of a heavy iron frame, at one end of which is a box containing a stout steel spring. A pointer connected with this spring moves over a graduated arc on the top of the box. On the frame are two movable blocks, or slides, one of which is attached to the spring, while the other may be carried backward and forward by a screw and crank.

The rod whose tenacity is to be tried is stretched between the two slides, and the crank is then slowly turned so as to pull upon the rod until it breaks. The force thus brought to bear upon the rod bends the spring; and the

position of the pointer when the rod breaks shows how much force it took to break it.

12. *Hardness and Softness.* — If we indent a piece of india-rubber with the finger-nail, or strike a piece of lead a smart blow with a hammer, we see that it is possible to displace the molecules of a solid. ***When it is easy to displace the molecules***, as in the case of wax, the solid is called *soft*; ***when it is difficult to displace them***, as in the case of glass, the solid is called ***hard***.

To find which of two solids is the harder, see which will scratch the other. The one which scratches is always harder than the one scratched. Diamond is the hardest solid known; hence it is used for cutting glass, which is also a very hard substance.

13. *Elasticity, Brittleness, Ductility, and Malleability.* — When molecules have been displaced, one of three results must follow, — they will return to their original positions as soon as they are left to themselves, or they will take up new positions, or they will fall entirely asunder.

If we bend a steel rod moderately, it straightens as soon as it is released; showing that displaced molecules sometimes tend to return to their former positions. This ***tendency of molecules to return to their original positions after being displaced*** is called ***elasticity***.

A steel rod may be bent a good deal, and yet straighten when released; but if it be bent beyond a certain point, it will no longer straighten, showing that the molecules, after they have been displaced beyond a certain limit, tend to remain in their new positions. The greatest extent to which the molecules of a solid can be displaced, and yet go back to their former positions, is called the ***limit of elasticity*** for that solid. All solids are found to be elastic, but they differ very much in the limit of their elasticity. The molecules of steel and india-rubber can

be displaced a good deal without becoming fixed in new positions, while those of glass and pipe-clay can be displaced but slightly.

If a glass rod be bent within a certain limit, it will straighten when released; but if it be bent beyond this limit, it will not remain bent, but will break. *When the displaced molecules cannot take up permanently new positions*, the solid is said to be *brittle*. Hard solids are likely to be brittle also; but hardness and brittleness are, as we have seen, entirely different things.

When the molecules after being displaced can take up permanently new positions, the solid is ordinarily described as *malleable* or *ductile*. It is said to be *malleable* when it can be *hammered or rolled out into sheets; ductile* when it can be *drawn out into wire.*

Gold is one of the most malleable of the metals. In the manufacture of gold leaf, it is hammered out into sheets so thin that it takes from 300,000 to 350,000 of them to make the thickness of a single inch.

Wire is made by drawing a rod of metal through a series of conical holes in a hardened steel plate. Each hole is a little smaller than the preceding, so that the rod becomes lengthened and diminished in thickness as it is drawn through one after another.

In the drawing of iron wire, the molecules are separated, yet the tenacity of the iron is greatly increased, so that fine iron wire is the most tenacious of substances. A bar one inch square of the best wrought-iron will sustain a weight of thirty tons; a bundle of wires one-tenth of an inch in diameter, containing the same quantity of material, will sustain a weight of from thirty-six to forty tons; and if the wires have a diameter of only one-twentieth or one-thirtieth of an inch, the same quantity will sustain from sixty to ninety tons. Hence cables made of fine iron wire twisted together are much stronger than

bars or chains of the same weight. The cables of suspension bridges are made in this way.

The following Table gives the most useful metals in the order of their tenacity, malleability (both under the hammer and the rolling-mill), and ductility: —

Tenacity.	Malleability under the Hammer.	Malleability under the Rolling-Mill.	Ductility.
Iron	Lead	Gold	Platinum
Copper	Tin	Silver	Silver
Platinum	Gold	Copper	Iron
Silver	Zinc	Tin	Copper
Zinc	Silver	Lead	Gold
Gold	Copper	Zinc	Zinc
Lead	Platinum	Platinum	Tin
Tin	Iron	Iron	Lead

14. *Solids are somewhat Compressible.* — Some metals are permanently diminished in bulk by hammering; and so also by the pressure to which they are subjected in the process of coining. The stone columns of buildings are frequently shortened by the great weight resting upon them. This was found to be the case with the columns supporting the dome of the Pantheon at Paris.

15. *The Molecules sometimes arrange themselves in Crystals.* — If alum be added to hot water as long as it will dissolve, and then the water be allowed to cool slowly, a part of the alum will be deposited on the bottom of the dish, not in a confused mass, but in beautiful and symmetrical forms, called *crystals.*

Melt some sulphur in a crucible, and let it cool slowly till a crust forms on the surface; then carefully break the crust, and pour off the remaining liquid. The crucible (Figure 5) will be found lined with delicate needle-shaped crystals.

Fig. 5.

eneral rule, the molecules tend to arrange themselves . The same solid usually s in the same form, but olids in different forms.

cases of crystallization : have already described, is first brought to the e, *that the molecules may* *dom of motion.* The building of a crystal out les is much like building a house out of bricks. s must be taken one by one and laid in regular re they are cemented together. So, in forming the molecules must be arranged one by one in der before they are fastened together by the force.

crystals of many solids can be obtained by dis- much of the solid as is possible in cold water, etting it away in a shallow dish where it will be dust and disturbance, and allowing the water ate very slowly. *The more gradual the for- he larger are the crystals.* The large crystals binets of minerals were probably centuries in The water in which the solid was dissolved way into a cavity of a rock, and there slowly d.

dency of the molecules to form crystals is strik- wn in cannon which have been many times in shafts of machinery and axles of car-wheels continually jarred. Such bodies often become d on breaking show the smooth faces of the hich have been formed. *The continued jar- s the molecules a slight freedom of motion,* ls are slowly built up.

olids are crystalline in structure which do not

appear to be so. Thus a piece of ice is a mass of the most perfect crystals, but they are so closely packed together that we cannot readily distinguish them.

16. *The Molecules cohere more strongly on some sides than on others.* — It is easy to cleave a piece of mica or other crystal in certain directions, but difficult to cleave it in other directions. The molecules cohere more strongly on some sides than on others. Iron and other solids are not so tenacious when crystalline in structure as when not crystalline. This is because the molecules in crystals are arranged in layers, so that the weakest sides are brought face to face.

17. *Annealing and Tempering.* — If melted glass be dropped into cold water, it forms the well-known *Rupert's drops*, which are so brittle that, if we break off the small end or scratch them slightly with a file, they fly in pieces. When glass is allowed to cool in the air at the ordinary temperature, it is also very brittle. In order to make it tough enough for ordinary use, it must be cooled very slowly, or *annealed.* This is done by passing it slowly through a long oven, which is kept very hot at one end and cool at the other.

Steel, also, when suddenly cooled from a high temperature, is very hard and brittle; but when slowly cooled, it is very tough and pliable. The process of giving steel various degrees of hardness is called *tempering.* The steel is first heated white hot, and then suddenly cooled by plunging it into cold water. It is thus rendered very brittle. It is then reheated, and allowed to cool slowly. When it is to be made quite hard, it is reheated but slightly; when quite soft, it is reheated a good deal. The more it is reheated, the softer it becomes on cooling. These different conditions of glass and steel are probably owing to differences in the arrangement of the molecules.

18. *Liquids have little Cohesion.* — The chief char-

acteristic of liquids is that the attractive and repulsive forces acting between the molecules are very nearly balanced, the attractive force being slightly the greater. Hence in liquids the cohesion is slight, and the molecules are free to move among themselves.

If a piece of lead be carefully measured, then melted and measured again, it will be found to have increased in bulk. Hence, *when any substance is in a liquid state, the molecules are farther apart than when it is in a solid state.* This explains why, in moulding bullets, the mould is never quite filled by the bullet.

There are a few exceptions to this rule. If, for instance, a bottle be filled with water and tightly corked, and allowed to freeze, the bottle will burst. The molecules of ice, then, must be farther apart than those of water.

Fig. 6.

19. *Liquids are but slightly Compressible.* — The apparatus represented in Figure 6 consists of a very thick vessel of glass closed at top and bottom. Within the vessel are a piston which can be moved by the thumb-screw at the top, and a glass bulb which is prolonged by a very fine tube, bent as represented. Fill the bulb and tube with any liquid, as water, and plunge the end of the tube in the mercury which covers the bottom of the vessel. Then fill the vessel with water, and apply pressure by turning the screw. The mercury will rise in the tube, showing that the liquid in the bulb has been compressed. This compression, however, is but slight, amounting at most to a few millionths of the bulk of the liquid.

20. *Liquids are perfectly Elastic.* — However much the screw, in the above experiment, may be turned down, or however long it may be left, the moment we loosen it the mercury will fall inside the tube to a level with the mercury outside; showing that liquids are perfectly elastic.

This elasticity is developed *only when the liquid is compressed;* that is, when the molecules have been brought nearer together. In whatever other way the molecules may be displaced, they show no tendency to return to their former positions.

21. *The Molecules in Liquids when left to themselves collect into Spheres.* — If a mixture of water and alcohol be made, which is just as heavy as sweet-oil, bulk for bulk, and a quantity of the oil be carefully introduced into the centre of this mixture by means of a dropping-tube, the oil will neither rise nor sink, but gather into a beautiful sphere. This shows that when the molecules of a liquid are left to themselves, they at once collect into spheres.

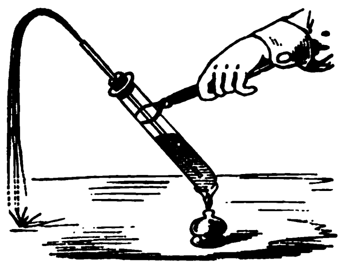
Rain-drops, dew-drops, and the manufacture of shot illustrate this tendency of the molecules of liquids. In making shot, melted lead is poured through a sieve at the top of a very high tower, and the drops in falling take the form of spheres, which become solid before they reach the bottom.

22. *Gases have no Cohesion.* — In gases, as has already been shown, the repulsive molecular force exceeds the attractive. Hence there is no cohesion in this state of matter, and the molecules move among themselves with greater freedom than those of liquids.

The molecules of any substance are farther apart in the gaseous state than in either the solid or the liquid state. Fill a test-tube nearly full of water, then close it tightly with a cork through which a fine tube passes nearly to

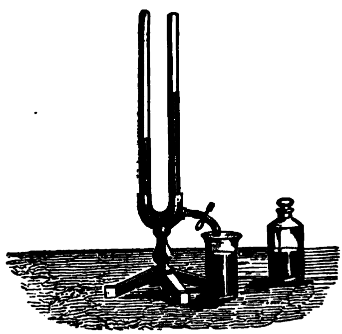
the bottom of the test-tube. Boil the water so as to convert a portion of it into steam, which is a gas, and the water will be driven forcibly out of the fine tube (Figure 7); showing that the steam occupies more space than the water from which it comes.

Fig. 7.



23. *Gases are readily Compressible.* — The Figure represents a U-tube closed at one end and open at the other, with a nipper-tap * at the bend. Pour in mercury enough to cover the bend. The closed end is now filled with air. Pour in more mercury and this column of air rapidly shortens; showing that gases are highly compressible.

Fig. 8.



24. *Gases are perfectly Elastic.* — Open the nipper-tap that the mercury may run out, and it is entirely driven out of the closed arm of the tube. To prove that it is the elasticity of the air which drives out the mercury from this arm, fill the closed arm and a part of the open arm with mercury, and open the nipper-tap. The mercury will flow out from the open arm, and not from the closed arm.

Air and other gases are perfectly elastic.

* See in Appendix, *Notes on Experiments.*

SUMMARY.

Matter is made up of particles too small to be seen, called *molecules*. (1, 2.)

These molecules are not in actual contact with one another. It is probable that the spaces which separate them are immense in comparison with the size of the molecules themselves. (3, 4.)

There is an *attractive molecular force*, which holds the molecules together, and a *repulsive molecular force*, which pushes the molecules apart. (5.)

These two molecular forces *act together*, and the *repulsive* molecular force is *increased by heat*. (6.)

There are *three states of matter*: the *solid* state, in which the attractive force is considerably the greater; the *liquid* state, in which the two forces are nearly equal; and the *gaseous* state, in which the repulsive force is the greater. (7.)

The force which holds together molecules of the *same* kind is called *Cohesion;* that which holds together molecules of *different* kinds, *Adhesion*. (8.)

Cohesion is the excess of the attractive over the repulsive molecular force. In *solids*, it is comparatively strong; in *liquids*, it is weak; in *gases*, it does not exist.

The properties of solids depend on the action of the cohesive force. (10.)

The *tenacity* of a solid is its power of resisting rupture. (11.)

A solid is called *hard* when it is difficult to displace its molecules; *soft*, when it is easy to displace them. (12.)

Elasticity is the tendency of the molecules, on being displaced, to return to their original positions. All solids are elastic, but differ greatly in the *limit* of their elasticity.

A solid is said to be *brittle* when its molecules cannot take up permanently new positions.

It is said to be *malleable* or *ductile* when they can take permanently new positions: *malleable*, when it can be hammered or rolled into sheets; *ductile*, when it can be drawn into wire. (13.)

Solids are somewhat *compressible.* (14.)

The cohesive force often arranges the molecules of a solid into regular forms called *crystals.* (15.)

The *cohesive force is stronger on some sides of the molecule* than on others. (16.)

The molecules are farther apart in the *liquid* than in the solid state; yet liquids are *less compressible* than solids. (19.)

Liquids are *perfectly elastic;* but their elasticity is developed only when the molecules are brought nearer together. (20.)

The molecules of a *liquid*, when acted upon only by cohesion, tend to collect into *spheres.* (21.)

In the *gaseous* state, the molecules are farther apart than in the liquid state. (22.)

Gases are readily *compressible*, and when compressed are *perfectly elastic.* (23, 24.)

ADHESION.

25. *Adhesion between Solids and Solids.* — Adhesion has already been defined as *the force which holds together unlike molecules.*

The sticking of the chalk to the blackboard, of the graphite of the pencil to paper, and of dust to furniture, prove the existence of this force between solids and solids. The use of the various cements also illustrates this force.

When solids are held together by cements, cohesion and adhesion are both brought into play. When, for instance, two pieces of wood are held together by means of glue, the adhesive force holds the wood on each side to the glue, and cohesion holds together the molecules of the glue.

When furniture breaks, we often see that the wood splits instead of separating from the glue. So also stones are sometimes cemented together so firmly that the stone itself will break sooner than separate from the cement. The *adhesive force between two solids is frequently stronger than the cohesive force of the solids* themselves.

26. *Adhesion between Solids and Liquids.* — If we dip the hand in water, it comes out wet. This fact, with others equally familiar, proves that there is also an adhesive force between liquids and solids.

27. *The Adhesion between a Liquid and a Solid is sometimes not strong enough to overcome the Cohesion of the Liquid.* — If a glass disk be suspended from one pan of a balance and counterpoised by weights, and then

brought in contact with mercury, it will require additional weight to raise the disk from the mercury, and the disk comes off dry. This proves, first, that there is adhe-

Fig. 9.

sion between glass and mercury, and, secondly, that this adhesion is not strong enough to overcome the cohesion of the mercury.

28. *The Adhesion between a Solid and a Liquid is sometimes strong enough to overcome the Cohesion of the Liquid.*—If a glass plate be laid upon the surface of water and then removed, it comes off wet, that is to say, covered with a film of water; showing that the adhesion between a solid and liquid is sometimes strong enough to overcome the cohesion of the liquid.

Since adhesion takes place only at the surface, it is evident that *we may increase the adhesion of a solid for a liquid by increasing the surface of the solid.*

If we take a stone, and break it in two, it evidently has all the surface it had before it was broken, and, in addition, the two surfaces exposed by the breaking. The more it is broken up, the more surface it exposes. The readiest way, then, to increase the surface of a solid is to pulverize it.

If pulverized bone-black be mixed with vinegar, or with wine, and the liquid be separated again by pouring the mixture upon unsized paper placed inside a funnel, the liquid that runs through will be colorless. All vegetable colors can be removed from liquids in the same way. The process is called *clarifying* the liquid.

Bone-black is obtained by burning bones in closed vessels. It is pulverized that it may present more surface. Other substances may be used for clarifying liquids. Next to bone-black, ordinary charcoal is the best and the most frequently used. The bone-black evidently removes the coloring matter by means of the adhesive force which exists between the two. The coloring matter adheres to the bone-black more strongly than to the liquid, or the two would not be separated.

29. *The Adhesion between a Solid and a Liquid is sometimes strong enough to overcome the Cohesion of the Solid.* — If some Epsom salts be put into water, the salts will speedily become liquid. The adhesive force between the water and the salts overcomes the cohesive force of the solid, since it reduces the solid to the liquid state.

30. *Three Cases of Adhesion between Solids and Liquids.* — We have, then, three well-marked cases of adhesion between solids and liquids: —

1st, When the adhesive force is not strong enough to overcome the cohesion of the liquid. In this case, the liquid *cannot wet* the solid.

2d, When the adhesive force is strong enough to overcome the cohesion of the *liquid*. In this case, the liquid can *wet* the solid.

3d, When the adhesive force is strong enough to overcome the cohesion of the *solid*. In this case, the liquid can *dissolve* the solid. The liquid which dissolves the solid is called a *solvent*, and the liquid in which the solid has been dissolved is called a *solution*.

31. *Heat promotes Solution.*—We find on trial that Epsom salts will dissolve more rapidly and in greater quantity in hot than in cold water. We have already found (1, 6) that heat tends to overcome cohesive force. As a general rule, solids dissolve in greater quantities and more readily in hot than in cold liquids; but there are exceptions, among which are lime and Glauber's salts.

32. *Capillarity.*—If one end of a fine and clean glass tube be put into water, the water will rise inside the tube above the surface of the water outside. If one end of such a tube be put into mercury, the mercury will fall inside the tube below the surface of the mercury outside. This action of liquids inside tubes is called *capillarity.* The force which draws some liquids into tubes and pushes others out, has been called *capillary force.* This name is a convenient one, though capillarity really results from the combined action of certain other forces.

We have seen that water will *wet* glass (28), while mercury will *not* (27). We have, then, two distinct cases of capillarity, corresponding to two cases of adhesion between solids and liquids; for *those liquids which will wet a tube are drawn into it,* while *those which will not wet it are driven out.* Mercury will wet zinc, and it is drawn into a tube of zinc, just as water is into a tube of glass.

Fig. 10.

We find by using glass tubes of different sizes, that the finer the tube, the higher the water rises and the lower the mercury falls; that is, the more marked is the capillarity. The word *capillary* comes from a Latin word (*capillaris*), which means *hair-like*. The force was called *capillary* because its action is most powerful in hair-like tubes. This force, however, acts in tubes of every size, and in fact a tube is not ne-

cessary for its action. Put two plates of glass together as represented in Figure 11, and then dip them into water or mercury. The water will rise between the plates, and the mercury will fall.

Fig. 11.

33. *Illustrations of Capillarity.*—A lamp-wick is full of tubes and pores; and capillary force draws the oil up through these to the top of the wick, where it is burnt. When one end of a cloth is put into water, capillary force draws the water into the tubes and pores of the cloth, and the whole soon becomes wet. In the same way, a lump of sugar, or other porous substance, soon becomes wet throughout, if a corner of it is put into water. Blotting-paper is full of pores into which the capillary force draws the ink. The use of a towel for wiping any thing which is wet depends on the same principle.

34. *Strength of the Capillary Force.*—When a piece of cloth is wet, it is quite impossible to wring or squeeze it dry. This shows that the capillary force which holds the water into the pores of the cloth is very strong. Many other facts prove the strength of the capillary force.

35. *Capillary Force never causes a Liquid to flow through a Tube.*—If we take a glass tube, in which the capillary force will raise water two inches, and put the tube into water so that not more than half an inch shall be above the surface, the water will not overflow the tube. If, however, the water be removed as soon as it comes to the top, more will rise to take its place.

When a lamp is burning, the oil is passing up continually through the wick, because it is burnt as soon as it reaches the top; but when the lamp is not burning

he oil does not overflow the wick. The wick of an lcohol lamp must be covered with a cap when not in use, or the alcohol will evaporate as fast as it comes to the top of the wick, and so all pass out of the lamp.

36. *Adhesion between Solids and Gases.* — If a piece of boxwood charcoal be put into a jar of ammonia gas over mercury, the mercury rapidly rises into the jar.* The ammonia gas, then, is drawn into the charcoal by an adhesive force; showing that there may be adhesion between the molecules of a solid and those of a gas. When a gas is taken up in this way by any substance, it is said to be *absorbed.*

When the ammonia gas is absorbed by the charcoal, it must occupy less space than before. When a gas is absorbed by a solid, then, the repulsive force of the gas has to be overcome. We know that cold helps to overcome the repulsive force (3). Hence we should expect that a solid would absorb a gas when cold more readily than when hot; and this is found to be true.

Heat, on the other hand, increases the repulsive force. If a solid which has absorbed a gas be heated, the repulsive force of the gas is increased, so that it finally overcomes the adhesion of the solid for the gas, which then leaves the solid. The charcoal is heated before it is put into the jar, in order to expel the air from its pores.

37. *Adhesion between Liquids and Liquids.* — If oil be poured upon water, the oil, which is the lighter, soon rises to the top and remains entirely separate from the water. If alcohol, which is also lighter than water, be poured into water, the two will thoroughly mix.† This proves that the molecules of the alcohol adhere to those of the water, and that this adhesion is strong enough to overcome the cohesion of the liquids.

* See, in Appendix, *Notes on Experiments.*

† This may be shown better by using colored water.

Nearly all liquids will mix when poured tog
though some will mix much more readily than oth

38. *Diffusion of Liquids.*—Put some colored al
into a tall glass jar, and then with a funnel car

Fig. 12.

pour in some water (Figure 12).
water will remain for a time a
bottom of the jar, and its sepa
from the alcohol will be sharpl
fined; but on standing a few day
two liquids will become thoro
mixed. This *mixing of liqui
being merely brought into con*
called *diffusion of liquids.* Di
liquids diffuse into each other
different rates; while some, as
water, will not diffuse at all.

39. *Osmose of Liquids.*—Fa
bladder air-tight to the end of
glass tube, fill the bladder with a
and put it into a vessel of wate
ure 13). The liquid will gradually rise in the
showing that the water has passed into the b
At the same time the alcohol passes slowly out and
with the water.

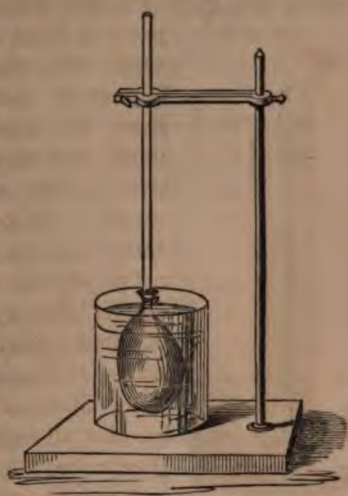
*The mixing of liquids when separated by a thi
brane or porous substance* is called *osmose of liq*

Liquids do not mix at the same rate when se
by a thin membrane or porous substance as wh
mix by simple diffusion. The rate of mixing is m
in a striking manner by the presence of the memb
porous substance.

40. *Adhesion between Liquids and Gases.*—
small glass jar inverted over mercury be fille
ammonia gas, and then pour some water over t
face of the mercury. Raise the jar carefully,

its mouth comes in contact with the water, the ses and completely fills the jar. The ammonia bed by the water, ; that the mole- the gas adhere to the water.

Fig. 13.



same gas is not d with equal read- all liquids. Am- gas, which is ab- so greedily by is not absorbed at mercury.

old and Pressure te Absorption. — a gas is absorbed quid, as when ab- by a solid (36), ecules are brought together and the ve force overcome. Both cold and pressure, as e seen, help to overcome this force; hence they he absorption.

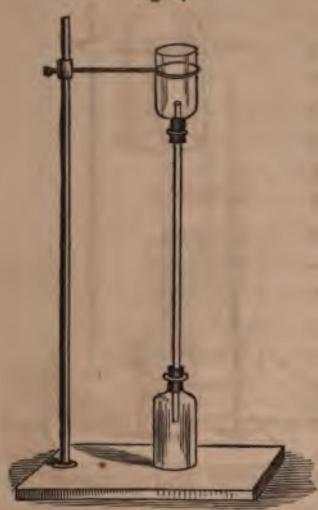
effect of pressure on the absorption is illustrated -water, which owes its agreeable taste mainly to sence of carbonic acid gas in the water. Water rbonic acid are brought in contact in the fountain, bjected to very great pressure. When the water is from the fountain, this pressure is removed; and bonic acid escapes in thousands of little bubbles, ; the liquid to foam, or *effervesce.*

nary *aqua ammonia* is water which has absorbed ia gas. If it be heated, the gas escapes. The creases the repulsive force of the gas, and thus nes its adhesive force for the liquid. This is the

ordinary way of freeing a liquid from a gas wh
has absorbed.

Common spring-water owes much of its pleasan
to the presence of carbonic acid and other gases w

Fig. 14.



absorbs from the air.
this water is boiled,
gases escape, and it be
very insipid. The co
agitation of running
helps it to absorb
since it is thus made t
sent more surface to th

42. *Diffusion of Ga*
Two bottles are con
by a long glass tube
ure 14). The lower
is then filled with ca
acid and the upper wi
drogen gas, which is
much lighter than ca
acid. After a time, th
drogen will be found to
passed down and mixed with the heavier carbonic
and the carbonic acid to have mixed with the hyd
in the upper bottle.

We may prove that there is carbonic acid in t
per bottle by pouring lime-water into it and shak
Carbonic acid makes lime-water milk-white, whi
drogen has no effect upon it.

The *mixing of gases when brought in cont*
called *diffusion of gases.*

Different gases diffuse into each other at very di
rates. As a general thing, the more the gases di
weight, the more rapidly they diffuse into each oth

43. *Osmose of Gases.*—A long glass tube is fa
air-tight, by means of a cork and sealing-wax, in

open end of an unglazed porcelain cup. The cup is then held so that the end of the tube dips beneath the surface of water, and a large bell-jar of hydrogen is held over the cup. There is an instant rush of bubbles from the end of the tube up through the water, showing that the hydrogen has passed through the pores of the cup and mixed with the air inside. Remove now the jar of hydrogen, and the water at once rises in the tube; showing that the hydrogen inside the cup has passed out through the pores to mix with the air outside.

Fig. 15.

The mixing of gases when separated by a porous substance or thin membrane is called *osmose of gases.*

SUMMARY.

Adhesion is the force which holds together molecules of *different kinds.*

It acts between molecules of solids and solids, solids and liquids, solids and gases; also between liquids and liquids, and liquids and gases. It is doubtful whether it acts between the molecules of different gases.

The adhesion between two solids is sometimes stronger than the cohesion of the solids themselves. (25.)

There are three cases of adhesion between solids and liquids: —

1st, When the adhesion is not strong enough to overcome the cohesion of the liquid, and the liquid cannot *wet* the solid.

2d, When it is strong enough to overcome the cohesion of the liquid, and the liquid can *wet* the solid.

3d, When it is strong enough to overcome the cohesion of the solid, and the liquid can *dissolve* the solid. (26–30.)

Heat generally promotes solution, since it helps to overcome the cohesion of the solid. (31.)

Capillary force acts upon liquids in tubes. Liquids which can wet a tube are drawn into it, while liquids which cannot wet it are driven out of it. The finer the tube, the more marked is the capillarity. (32.)

The capillary force is very strong; but acting alone it never makes a liquid flow *through* a tube. (33, 35.)

When a gas is absorbed by a solid or by a liquid, the adhesive force between the molecules of the solid or liquid and those of the gas must be strong enough to overcome the repulsive force of the gas. (36, 40.)

Heat hinders absorption, since it increases the repulsive force between the molecules of the gas. Hence gases absorbed by solids or liquids can be separated from them by means of heat. (36, 41.)

The same gas is absorbed by some solids or liquids more readily than by others. (40.)

The adhesive force between the molecules of different liquids causes the liquids to mix. The mixing of liquids on mere contact with each other is called *diffusion* of liquids. (38.)

Liquids also mix when separated by a thin membrane or porous substance. This mixing is called *osmose* of liquids. (39.)

Gases, like liquids, mix by *diffusion* and by *osmose*. (42, 43.)

MECHANICS.

PRESSURE.

WEIGHT.

44. *Matter is acted upon by Gravity.*—Thus far we have been dealing with forces which act between the *molecules* of matter. We are now to study a force which acts between *masses* of matter. When a stone falls to the earth, it is because this force acts between the stone and the earth to draw them together. We know that the moon is continually moving round the earth. Were it not for this force acting between these two great masses, the moon would fly off in a straight line, and we should never see her again. As it is, while moving onward, she is all the while falling towards the earth, and her path is thus bent from a straight line into a curve. It is found that the strength of this force *diminishes as the square of the distance increases;* that is, at double the distance its strength is one-fourth, at thrice the distance one-ninth, and so on. It can be proved that the moon obeys this law and falls towards the earth just as fast as a stone would fall if it were as far off.

It is the same force which keeps the earth in its pa about the sun, and which guides all the stars of he in their appointed courses. It acts upon every m matter in the universe, from the dust that floats air, to moons and planets and suns, compar

whose vast bulk this earth of ours is a floating particle of dust. This force is called *gravity.**

45. *Weight.* — When a stone is held in the hand, it is felt to press downward. This is because gravity is drawing it towards the earth. The *downward pressure which gravity causes a body to exert* is called its *weight.*

When different bodies, as iron and wood, are taken in the hand, it is easy to feel that some are heavier than others; but it is not so easy to tell exactly how much they differ in weight.

46. *The Spring Balance.* — But the weight of a body may be made to bend a spring, and, when different bodies are made to bend the same spring, we can readily tell how much heavier one is than another by seeing how much more it bends the spring. If it bends the spring twice as much, it is twice as heavy; and if three times as much, it is thrice as heavy. An instrument for finding the weight of a body in this way is called a *spring balance;* and one form of it is shown in Figure 16. It consists of a steel spring wound into a coil. One end of this coil is fastened to a ring, and the other to a hook. The body to be weighed is fastened to the hook, and the whole raised by the ring. The weight of the body straightens or draws out the spring. A pointer moving over a plate in front, which is divided into equal parts, shows how much the spring has been drawn out. A body which will straighten the spring a certain amount

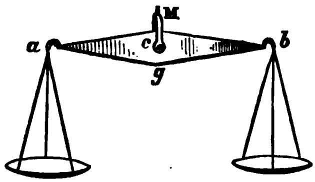
Fig. 16.

* We have already referred (see foot-note on page 4) to the analogy between the molecules in a mass and the great ... in solar and stellar systems. The analogy can be exte... the forces acting among the units which make up the ...

is said to weigh a pound; one which will straighten it half as much, half a pound; one fourth as much, a quarter of a pound; twice as much, two pounds; and so on.

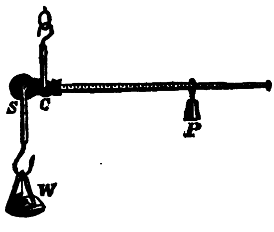
47. *The Balance.*—Another instrument for finding the weight of a body is called a *balance*, and is shown in Figure 17. It consists of a bar turning on a pivot in the centre, and having pans hung from each end for holding the body to be weighed and the *weights*, which are pieces of iron or brass whose weight is known. The body to be weighed is placed in one pan, and weights are put into the other until they balance it. The body weighs as much as the weights used.

Fig. 17.



48. *The Steelyard.* — Yet another weighing instrument is the *steelyard*, shown in Figure 18. It differs from the balance in having one long and one short arm. The weight P can be moved upon the long arm, and shows the weight of the body by its distance from C.

Fig. 18.

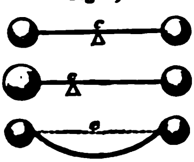


THE CENTRE OF GRAVITY.

49. *The Centre of Gravity.* — The centre of gravity of a body is a point such that *the force of gravity acting upon the part of the body on one side of this point balances the force of gravity acting upon the part on the opposite side, no matter how the body may be placed.*

50. *The Centre of Gravity is not always in the Body itself.* — If a straight strip of metal or wood be fastened to the sides of a ring so as to pass through its centre, it will be found that the ring will rest in any position when the centre is supported; and that it will not thus remain at rest on any other point. The centre of gravity, then, of a ring which is exactly alike throughout its whole extent is at the centre of the ring. If one part of the ring is heavier than the other, the centre of gravity will be found to be between the centre and the heavier part.

Fig. 19.



When two balls of the same weight are connected by a straight rod (Figure 19), the centre of gravity will be found to be at the centre of the rod. If one ball be twice as heavy as the other, the centre of gravity will be in the rod at a point twice as near the heavier ball as the lighter ball. If the heavier ball be three times the weight of the lighter ball, the centre of gravity will be thrice as near this ball as the other.

If the balls are connected by a curved rod, the centre of gravity will no longer be in the rod, but in a straight line which joins the balls. Its distance from the balls will be as explained above.

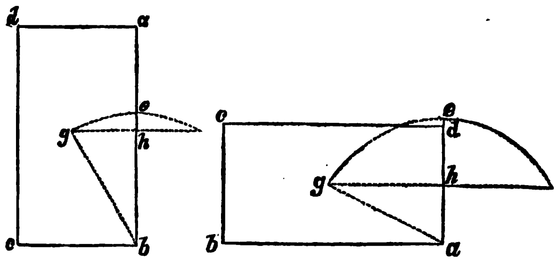
51. *Equilibrium.* — When a body is *at rest*, it is said to be *in equilibrium*. When it is *at rest in such a position that on being slightly disturbed it again returns to this position*, it is said to be in *stable equilibrium*. When it is *at rest in such a position that on being slightly disturbed it seeks a new position of rest*, it is said to be in *unstable equilibrium*. When a body *remains at rest equally well in any position*, it is said to be in *indifferent equilibrium*.

52. *The Centre of Gravity always seeks the* [illegible] *Point.* — In every case, it will be found that the ce[illegible]

gravity of a body seeks the lowest position that it can take. Hence, when a body is so situated that its centre of gravity is *raised* by tipping it in any direction, it is in *stable* equilibrium; when any disturbance of the body tends to *lower* its centre of gravity, it is in *unstable* equilibrium; when, on being disturbed, its centre of gravity *neither rises nor falls*, it is in *indifferent* equilibrium.

In Figure 20, *g e* shows the path which the centre of gravity *g* must take when the body is tipped. Until *g* reaches the point *e*, the body tends to go back, because in so doing the centre of gravity would fall; but as soon as *g* passes *e*, the body tends to go over, because in so doing the centre of gravity would fall. *h e* shows how much the centre of gravity must be raised to overturn the body; and this distance is seen to be greater when the

Fig. 20.

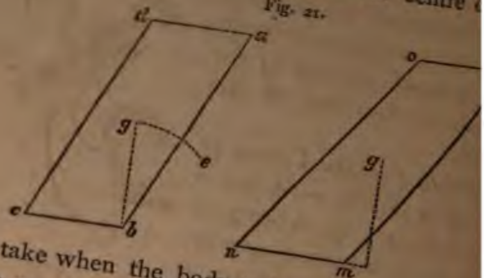


body is resting on the side *a b* than when it is resting on the side *b c*. It will be found that much more force will be required to overturn it in the latter case than in the [illegible]her. Hence, *the more the centre of gravity of a* [illegible] *has to be raised in order to overturn it, the more* [illegible] *its equilibrium.*

[illegible]ill also be seen from Figure 20 that *the broader* [illegible]*se of a body compared with its height, the more* [illegible] *its equilibrium.*

If, however, the body is *not upright*, it m[illegible] *stable* equilibrium even when *the base is* [illegible] Figure 21, g e is the path which the centre [illegible]

Fig. 21.



must take when the body a b c d is overturned; [illegible] will be seen that, as soon as g is [illegible] at all in the direction g e, it begins t[illegible] and the body will go over. In the [illegible] l m n o, the centre of gravity g is not [illegible]ported, and the body will fall over of it[illegible]

Fig. 22.

It is evident, then, that a body may [illegible] and yet be in equilibrium, provided [illegible] *centre of gravity is directly over* [illegible] *point of the base.* If this point be well within the base, the equilibrium may be very stable, as in the case of the famous leaning tower at Pisa.

Fig. 23.

On the other hand, a body may be in *stable* equilibrium even when *the base is very narrow.* Thus a cork may rest upon the point of a needle, and yet be in stable equilibrium. This may be proved by sticking two forks into the cork, as shown in Figure 22. The forks bring *the centre of gravity below the point of support,* so that the cork cannot be tipped without raising the

centre of gravity. In the same way, the image in Figure 23 is balanced on its toe by means of the two heavy balls beneath. So, too, in the "prancing horse" (Figure 24) the centre of gravity is brought below the point of support by the leaden ball at the end of the curved rod.

Fig. 24.

53. *How to find the Centre of Gravity of a Solid.* — When a stone, as in Figure 25, is hung by the cord A, the centre of gravity must be directly under the point of support; that is, somewhere in the line $A\ B$. If the same stone be hung by the cord C, its centre of gravity must still be below the point of support, somewhere in the line $C\ D$. Since the centre of gravity is in both the lines $A\ B$ and $C\ D$, it must be at the point G, where they cross.

Fig. 25.

To find the centre of gravity of a solid, then, *suspend it from any point of its surface by means of a cord, and notice the direction which the cord takes. Then suspend it from another point, and again notice the direction of the cord. The point within the body where lines drawn in these directions would cross each other will be the centre of gravity.*

Of course, if the solid be of *regular shape* and of *…rm density*, the centre of gravity is at the *centre …agnitude.*

SUMMARY.

Matter is acted upon by *gravity*, which gives it *weight*. (44, 45.)

The weight of bodies may be found by the *spring balance* (46), the *balance* (47), or the *steelyard* (48).

A point can always be found such that the force of gravity acting upon the part of a body to the right of it is always balanced by the force of gravity acting upon the part to the left of it, no matter in what position the body may be placed. This point is called the *centre of gravity*, and sometimes lies within a body and sometimes without it. (49, 50.)

A body at rest is *in equilibrium*. Its equilibrium may be *stable*, *unstable*, or *indifferent*. (51.)

The centre of gravity always *seeks the lowest position* which it can take. The *stability* of equilibrium depends upon the position of the centre of gravity, and upon how much it must be raised to overturn the body. (52.)

The centre of gravity of a solid may be found by suspending the body from two points of its surface. (53.)

PRESSURE OF LIQUIDS.

54. *How to find the Weight of a Liquid.* — If we weigh a cup and then fill it with water and weigh it again, we shall find that it weighs more in the second case. Liquids, as well as solids, are acted upon by gravity, which causes them to exert a downward pressure. The weight of the water in the cup is the weight of the cup when full of water *less* the weight of the empty cup. If the cup be filled with quicksilver, it will be found to wei[illegible]uch more than when filled with water; show[illegible]ome liquids are heavier than others.

55. *Liquids when acted upon by Gravity press, not only downward, but also upward and sideways.*—Fix a long tube into the top of a wooden cask, and put a stop-cock into the top, and another into the side of the cask. Fill the cask and the tube with water, and open the stop-cocks, and the water will be driven out of both. This shows that the water in the cask presses upward and sideways as well as downward.

The pressure which liquids exert sideways is called *lateral* pressure.

56. *The Upward, Downward, and Lateral Pressures are equal for the same Depth of Liquid.*—In Figure 26, we have a glass vessel, into the top of which are inserted three glass tubes of exactly the same size, with their mouths at the same distance from the bottom. One of these tubes opens downward, one upward, and one sideways. If we fill the vessel with water, through the funnel, the liquid rises to the same height in all three tubes. Now it is the upward pressure which causes it to rise in the tube opening downward, the lateral pressure which causes it to rise in the tube opening sideways, and the downward pressure which causes it to rise in the tube opening upward; and since the tubes are all of the same size, and the water rises to the same height in each, these pressures are all evidently equal.

Fig. 26.

57. *The Upward, Downward, and Lateral Pressures of a Liquid increase with the Depth, but are not altered by the Size or Form of the Vessel which holds the Liquid.*—The more water we pour into the vessel, in Figure 26, the higher the [illegible] rises in the tubes. The upward, downward, and [illegible] pressures increase

with the depth of the liquid, since the lower layers of molecules are themselves acted upon by gravity, and have also to sustain the pressure of the water above them.

That the pressure is independent of the size and shape of the vessel is seen when vessels of different sizes and shapes are connected (Figure 27), and a liquid is poured into one of them. It rises to the same height in all.

Fig. 27.

58. *When a closed Vessel is filled with a Liquid and any additional Pressure is brought to bear on any Particle of this Liquid, every Particle is made to exert the same additional Pressure, upward, downward, and sideways.* — Suppose the four tubes in Figure 26 are all of exactly the same size, and that the vessel is full of water. Pour water into the left-hand tube until it rises to the line *c d*. The water rises in all the tubes to the same height. The water poured into the first tube brings an additional pressure to bear upon the particles of water at its mouth, and it is the additional pressure which the particles at the end of the other tubes are made to exert that causes the water to rise in them. Since they are all of the same size, there must be the same number of particles at the end of each; therefore, the particles at the end of the three tubes are made to exert the sa[illegible]ure ditional pressure upward, downward, and sidew[illegible] that brought to bear upon the particles at the [illegible] the left-hand tube.

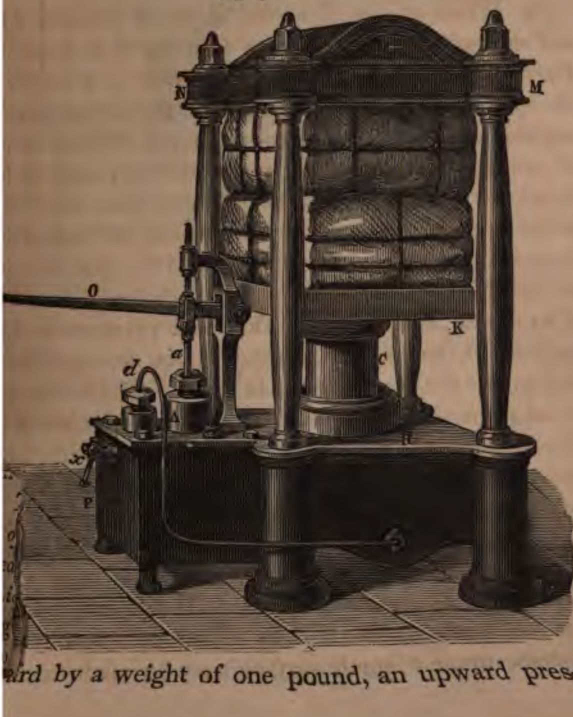
59. *The Hydrostatic Press.* — It follows, from [illegible] has just been shown, that by means of a liquid a[illegible] *pressure* upon a small surface may be made to e[illegible]

pressure upon a large surface. In Figure 28, we wo cylinders, with a plunger, or piston, in each.

Fig. 28.

se that the surface of the larger piston, P, is thirty that of the smaller, p; if the latter is pressed

Fig. 29.

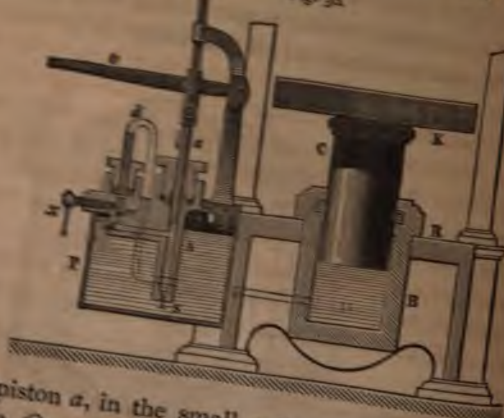


ard by a weight of one pound, an upward pres-

sure of one pound will be brought to bear
portion of the surface of P equal to that
whole upward pressure on P will then be
the downward pressure on p. If the surface
been sixty times that of p, one pound on the la
have balanced sixty on the former; and so on.

Advantage is taken of this fact in the constr
the hydrostatic press, shown in Figures 29 and 3
two cylinders A and B are connected by the

Fig. 30.



The piston a, in the small cylinder A, is worked by
handle O, and forces water into the large cylinder
where it presses up the piston C. If the end
piston C is 1,000 times as large as that of the pis
a pressure of 2 pounds on a would exert a press
2,000 pounds, or one ton, upon C. If a man in
the handle O forces down the piston a with a
of 50 pounds, he would bring to bear upon C a
of 25 tons.

This press is used for pressing cotton, hay, clo
into bales, for extracting oil from seeds, testing
boilers, etc., and for raising ships out of the water

). *Springs and Artesian Wells.*—All natural col-
ons of water illustrate the tendency of a liquid to
its level. Thus, the Great Lakes of North America
be regarded as a number of vessels connected to-
ier, and hence the waters tend to maintain the same
l in all. The same is true of the source of a river
l the sea, the bed of the river connecting the two like
ipe.

Springs illustrate the same fact. The earth is com-
ed of layers, or *strata*, of two kinds; those through
ich water can pass, as sand and gravel, and those
ough which it cannot pass, as clay. The rain which
s on high ground sinks through the soil until it reaches
yer of this latter kind, and along this it runs until it
ls some opening through which it flows as a spring.

t is the same with *Artesian wells*. These wells de-
their name from the Province of Artois in France,
first part of Europe where they became common. It
ld seem, however, that wells of the same kind were
le in China and Egypt many centuries earlier.

n Figure 31, suppose *A B* and *C D* to be two strata of
, and *K K* to be a stratum of sand or gravel between

Fig. 31.

n. The rain falling on the hills on either side will
r down through this sand or gravel, and collect in
hollow between the two strata of clay, which prevent

its escape. If now a hole be bored down to $K K$, the water, striving to regain its level, will rise to the surface at H, or spout out to a considerable height above it.

An Artesian well in Paris has a depth of 548 metres, or about 1,800 feet, and the water flows out at the rate of 656 gallons a minute, or nearly a million gallons a day. One in this country, at St. Louis, is 2,199 feet deep, and affords 75 gallons a minute.

61. *A Body is buoyed up when placed in a Liquid.* — If a stone be weighed under water, it will seem to be lighter than when weighed in the air.

We have already seen that, at the same depth in a liquid the upward and downward pressures are equal, but that these pressures increase with the depth. The bottom of the stone in the above experiment being deeper in the water than the top, the upward pressure of the water against the bottom of the stone is greater than the downward pressure upon the top of the stone. The stone is accordingly lifted up a little when plunged under water, and, being thus buoyed up, seems to be lighter than in the air.

Fig. 32.

62. *A Body is buoyed up in Water by a Force just equal to the Weight of the Water which it displaces.*—In Figure 32, A is a cup into which the cylinder B exactly fits. This cup, then, will hold just as much water as B displaces when under water. Hang this cup and cylinder to the hydrostatic balance, and balance it with weights. Immerse the cylinder B in a vessel of water, and we find that it is more than balanced by the weights. Now care-

l the cup *A* with water from the vessel, and
p and cylinder are seen to be again just bal-
by the weights. This shows that a body when
ed in water is buoyed up by a force just equal
weight of the water which it displaces.
ourse, if a solid weighs exactly as much as the
t displaces when fully immersed, it will neither
r sink in the water. If it weighs more than the
it displaces, it will sink; if less, it will rise.
a body floats upon the water, it displaces exactly
weight of water. It is well known that a lump
will sink, but the same lump of iron may be
red out into a vessel which will displace its own
of water without being wholly immersed.
is way, ships may be made of iron which will
pon water as well as ships made of wood.

SPECIFIC GRAVITY.

Substances vary in Density. — The same bulks
rent solids and liquids are found to be very differ-
weight. A substance which *weighs more, bulk
lk*, than another substance is said to be more
or to have a greater *density*. It is often desirable
v the relative weights of the same bulks of bodies
vary in density. In such cases, it is convenient
pare the weight of each substance with the weight
e given substance; and *water* is taken for this
e. *The weight of a given substance compared
he weight of the same bulk of water* is called its
gravity.
Specific Gravity of Solids. — To find the specific
of a solid or liquid, we must know the weight of
stance and that of the same bulk [illegible]ter.
weight of a bulk of water [illegible] hat of the

solid can be found by weighing the solid in subtracting its weight in water from its wei The difference of these weights is (62) just e weight of the water it displaces; and this is a bulk of water just equal to its own bulk.

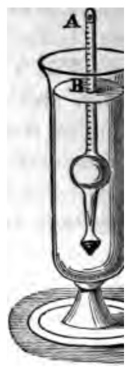
Hence we have the rule: ***divide the wei body by its loss of weight in water, and th will be its specific gravity.***

If the body will not sink in water, fasten it of iron or other substance which will make find the weight lost by the two in water. Th between what both lose and what the iron we loses will, of course, be what the lighter body

65. *Specific Gravity of Liquids.*—The sp ity of liquids is most conveniently found by n instrument, shown in Figure 33, called a *h*

Fig. 33.

Fig. 34.



It consists of a hollow glass cylinder, with scale-pan above, and a small bulb filled wi below, by which it is made to float upright The instrument is placed in water, and added until it sinks to a point marked upo

weight of the hydrometer, together with the weights
e pan, is equal to the weight of the water displaced
. If now the instrument be placed in a liquid of dif-
t density, as alcohol, and made to sink by weights
e mark on the stem, the weight of an equal bulk of
liquid can be found. Of course, *the specific grav-
of the liquid* will be *the weight of the liquid
ded by the weight of the water.*

more common form of hydrometer is shown in Fig-
34. It consists of a glass tube and bulb loaded with
ury at the bottom. This, when put into a liquid in
h it will float, always displaces just its own weight
. It is first put into pure water, and the point to
h it sinks is marked upon the stem. If it be now
into a liquid of less density, it will sink deeper; if
one of greater density, it will not sink so deep. By
ns of the scale on the stem, the specific gravity of the
d into which it is put is indicated.

nother way to find the specific gravity of a liquid is
following: Fill a small bottle with water, and then
the liquid, and find the weight of each; then di-
the weight of the liquid by the weight of the water,
the quotient will be the specific gravity required.
specific gravity bottle is a bottle which is made to
a definite weight of water, as 1,000 grains. If it
s 790 grains of alcohol, the specific gravity of the
ol is .79; if it holds 1,860 grains of sulphuric acid,
pecific gravity of the acid is 1.86; and so on.

ain, since the weight which a body loses when im-
ed in a liquid is equal to the weight of its own bulk
at liquid (23), we can find the specific gravity of
uid by *dividing the weight which a body loses
hat liquid by the weight which it loses in water.*
, if a piece of copper loses 200 grains when weighed
ater, and 158 grains when weighed in alcohol, the

specific gravity of the alcohol is equal to 158 divided by 200, or .79.

SUMMARY.

Liquids have weight, and press upward, downward, and sideways. (54, 55.)

The upward, downward, and lateral pressures are always equal for the same depth of the liquid. (56.)

These pressures increase with the depth of the liquid, but are not altered by the size or shape of the vessel. (57.)

When any pressure is brought to bear upon one particle of a liquid, every particle is made to press with the same force upward, downward, and sideways. (58.)

On this account, when a small force acts upon a few particles of a liquid, an enormous force may be brought to bear on a large surface in contact with the same liquid. This is illustrated by the *hydrostatic press*. (59.)

Springs and Artesian wells illustrate the tendency of water to seek a level in connected vessels. (60.)

A body is buoyed up in water by a force equal to the weight of the water which it displaces. (61, 62.)

The *specific gravity* of a solid or liquid is the weight of the solid or liquid compared with the weight of the same bulk of water. (63.)

To find the specific gravity of a solid, divide its weight by its loss of weight in water. (64.)

The *hydrometer* is an instrument for finding the specific gravity of liquids. (65.)

☞ The *Problems* on the pressure and weight of liquids, given in the Appendix, are intended to be used at this point.

THE PRESSURE OF GASES.

5. *Gases have Weight.* — Weigh very carefully a copper globe when filled with air; then weigh it in after exhausting the air from it, and it will be nd to weigh less than before. This shows that air weight, and the same is true of all other gases.

7. *Gases, like Liquids, press upward, downward, d sideways.* — Figure 35 represents two brass hemi-

Fig. 35.

Fig. 36.

eres, some four inches in diameter, the edges of ich are made to fit tightly together. While the nispheres contain air, they can be separated with e, since the outward pressure is just balanced by the ard pressure; but when the air within is pumped it is very hard to pull them apart. Since it is ally difficult to do this, in whatever position the nispheres are held, the experiment shows that *the presses in all directions.*

'his piece of apparatus is called the *Magdeburg*

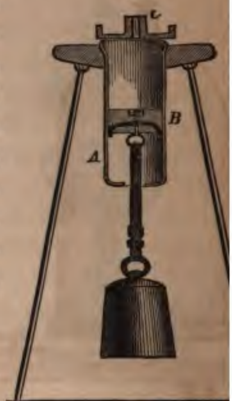
hemispheres, from Otto von Guericke, of Magdeb[urg]
by whom it was invented.

If a small bell-jar, open at both ends, be covered w[ith]
the palm of the hand, and the air be then exhau[sted]
from it, the hand will be held down with consider[able]
force by the pressure of the air upon it.

If a wet bladder be tied over the same bell-jar [and]
dried, and the air be exhausted as before, the bla[dder]
will burst with a loud noise.

These two experiments illustrate the downward p[res-]
sure of the air.

Fig. 37.



In Figure 37, *A* is a strong glass cylinder, open at both ends; *B* a piston, working air-tight within it; and *C* a brass plate, covering it closely, and having a hole in the centre to which a hose may be screwed for connecting it with the air-pump. When the air is exhausted from the cylinder, the piston rises, even if a heavy weight be fastened to it.

This experiment affords a very striking illustration of the upward pressure of the air.

Fig. 38.

68. *Gases have an Expan[sive] Force.* — If an india-rubber bag, [par-]tially filled with air, be closed [air-]tight and placed under the rece[iver] of the air-pump, the bag fills ou[t, as] shown in Figure 38, when the [air] is exhausted from the receiver. [All] gases thus tend to expand.

69. *The Air-Pump.* — An ins

ment for removing the air from a vessel is called an *air-pump*. One form of it is shown in Figure 39. It consists of a cylinder, in which a piston moves air-tight. In this piston is a valve opening upward. At the top of the cylinder is another valve also opening upward. The bottom of the cylinder is connected with the pump-plate by a tube. On this plate is placed the vessel, or *receiver*, from which the air is to be exhausted. As the

Fig. 39.

piston is forced down, the expansive force of the air below pushes open the valve in the piston to get into the space left behind it. When the piston is drawn up again, the expansive force of the air above closes this valve and opens the valve at the top of the cylinder, so that this air escapes. The expansive force of the air in the tube and receiver causes it to fill the space behind the piston. When the piston is again pushed down, the

downward pressure of the air outside closes the valve at the top of the cylinder, while the expansive force of the air below opens the valve in the piston, and some of the air passes through it. On drawing up the piston again, this air is removed as before. By continuing this process, the air is nearly all withdrawn from the receiver. It cannot be wholly withdrawn, because as it becomes more and more exhausted, the expansive force becomes less and less, until at last it is not sufficient to open the valve in the piston.

70. *A Body is buoyed up in the Air.* — If a hollow sphere be balanced in the air by a piece of lead, and then the whole apparatus be put under the receiver of an air-pump and the air exhausted, the lead will no longer balance the sphere. This shows that a body is buoyed up in the air as well as in a liquid (61). Bodies seem to be lighter in the air than in a ***vacuum*** (that is, *a space from which the air has been exhausted*), for the same reason that a body seems lighter in water than in the air. The upward pressure of the air upon the bottom of the body is somewhat greater than the downward pressure upon the top of the body. A body in the air, then, is *buoyed up by a force just equal to the weight of the air which it displaces.* If a body weighs more than the air it displaces, it sinks through the air; if it weighs less than the air it displaces, it rises in the air.

71. *Balloons.* — Balloons rise in the air because *they are filled with some substance which makes them lighter than the air which they displace.*

Fig. 40.

If a glass bulb and tube filled with air be arranged, as in Figure 40, with the end of the tube under

r, and the bulb be heated by means of a lamp, air in it expands, and a part of it is driven out in bles through the water. This shows that *air exds when heated.*

aper balloons are sometimes made which are sent by fastening a light just under an opening in the om of the balloon. The light heats the air inside, causes it to expand, and a part to pass out. The ainder is then lighter than the air displaced by the oon, which consequently rises. Large balloons are le of strong silk, and filled with some very light gas, as coal-gas. This makes the balloon so much ter than the air it displaces, that it will rise, carrying a car with two or three persons in it.

Fig. 41.

72. *The Pressure of the Atmosphere will sustain a Column of Liquid in an inverted Vessel.*—Fill a glass jar with water and invert it in a dish of water, keeping the mouth of the jar all the time under water; and the liquid will not flow out of the jar when it is raised. Now place the dish and jar under the receiver of an air-pump, and exhaust the air; and the water will flow out from the jar. This shows that it is the pressure of the atmosphere on the surface of the water in the dish which keeps the water in the inverted jar.

73. *The Atmospheric Pressure will sustain a Column of Mercury about* 30 *Inches high.* — If a glass tube closed at one end and about 34 inches long be filled with mercury, and inverted in a cup of mercury, as shown in Figure 41, a part of the mercury will run out, leaving a column about 30 inches high in the tube.

74. *The Atmospheric Pressure is equal to about* 15 *Pounds to the Square Inch.* — If the tube in the above experiment be one inch square, it follows, from the way in which liquids press, that the downward pressure at the bottom of the tube will be just equal to the downward pressure of the atmosphere on each square inch of the surface of the mercury in the vessel.

If now we weigh the mercury in the tube, we shall find that there are about 15 pounds of it. This column of mercury then exerts a pressure of 15 pounds at the bottom of the tube. The air then presses with a weight of 15 pounds upon every square inch of surface. We do not perceive this great pressure, because the air presses equally in every direction.

75. *The Atmospheric Pressure varies from Day to Day.* — If a glass tube be filled with mercury, and then inverted in a cup of mercury and left standing, and the height of the mercury column noted from day to day, it will be found to vary considerably, being sometimes as much as two inches higher than at other times. This variation must be due to changes in the pressure of the air.

76. *The higher the Place, the less the Atmospheric Pressure.* — If the tube just described be carried to the top of a mountain, the mercury will fall considerably. This shows that the atmospheric pressure becomes less, the higher we go above the surface of the earth.

The atmosphere is a great ocean of air which surrounds the earth, and at the bottom of which we live, as the fishes live at the bottom of the sea. The changes in

the height of the mercury just described show that the pressure increases with the depth.*

77. *The Barometer.*—An *instrument for measuring the pressure of the atmosphere* is called a *barometer*.

Fig. 42.

One form of it is shown in Figure 42. It consists of a cup and tube filled with mercury, as in the experiment illustrated by Figure 41. These are fastened to a wooden frame. At the upper part of the tube, there is a scale with a sliding index, for measuring the height of the mercury. *H* is a thermometer.

The mercury is often put into a leather bag instead of an open cup as here, since it is less likely to be spilled. As the leather is flexible, the pressure of the air is brought to bear upon the mercury through the bag.

78. *Uses of the Barometer.*—When we have found at what rate the atmospheric pressure diminishes as we go up, we can readily find the height of mountains by means of the barometer. The difference between the readings of the barometer at the level of the sea and at the top of the mountain, will show how much the pressure has diminished, and from this we can find the height of the mountain.

The barometer is also of considerable use in indicating the approach of storms, especially of violent winds. It has been observed that such storms are very likely to occur immediately after a sudden diminution of atmospheric pressure, which is shown

* See, in the Appendix, the chapter on *The Physics of the Atmosphere*.

by a rapid fall of the mercury. On the other hand, a gradual rise of the mercury usually indicates the approach of fair weather.

The mere *height* of the mercury tells us little about the weather, but a careful study of its *movements* enables us to judge pretty accurately what changes are likely to occur in the weather.

79. *Pumps.*—As water is somewhat more than thirteen times lighter than mercury, the pressure of the atmosphere will sustain a column of this liquid about thirteen times thirty inches in height, or considerably more than thirty feet. If the tube is open at the top, it is necessary to remove the air from it, before the water will rise into it. An instrument for raising water in this way is called a *pump*.

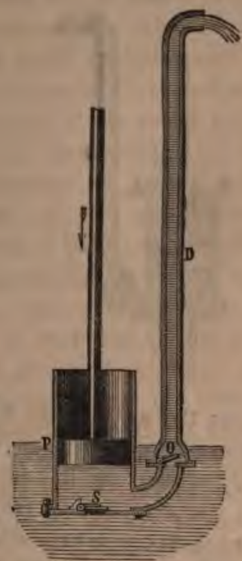
The common *lifting-pump* is shown in Figure 43. It is really an air-pump. When the piston *P* is forced down, the air below it, by its expansive force, opens the valve *O*, through which it escapes. When the piston is drawn up again, the valve *O* is kept shut by the pressure of the air above, and the air in *A* expands, pushes open the valve *S*, and rushes into the vacuum above. The air being thus partly removed from *A*, the pressure of the air upon the water in the well outside is greater than that inside the pipe, and consequently forces the water up the pipe and through the open valve *S*. When the piston is pushed down again, the pressure of the water in the cylinder shuts the valve *S*, and opens the valve *O*. The water thus gets above the piston, which, on going up again, lifts it so that it flows out at the spout, as shown in the figure.

Figure 44 represents the *force-pump*. In this pump, the piston *P* is solid. When it is drawn up, the water below, by its upward pressure, opens the valve *S*, and fills the cylinder. When the piston is pushed down, the

valve S being shut by its own weight and the pressure of the water upon it, the water is forced up through the

Fig. 43.

Fig. 44.



valve O into the pipe D. When the piston goes up again, the valve O is closed by its own weight and that of the water above, the valve S opens, and the cylinder is filled as before.

In Figure 45, we have these two pumps combined. The air is pumped out through the valves S and O, and the water is forced up into the cylinder through the pipe A and the valve S, just as it was in the lifting-pump; and the water is then forced through the valve O and the pipe D, as in the force-pump, just described.

In both these forms of force-pump, the water is driven out of the pipe D only when the piston is going down. It may be made to flow out in a steady stream by adding an air-chamber above the valve O, as shown in Figure 46. As the water is forced into this chamber, it com-

Fig. 45.

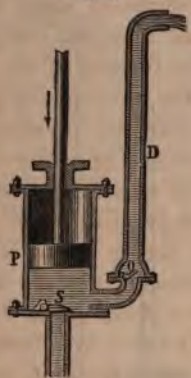
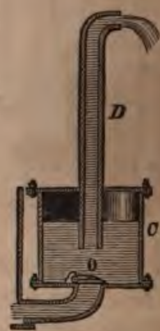


Fig. 46.



presses the air, which, by its expansive force, exerts a continuous pressure on the water, and drives it in a steady stream up the pipe.

In the *fire-engine*, two force-pumps are usually connected with one air-chamber. The pumps are so arranged that the piston of one is going down while that of the other is going up, thus forcing water into the air-chamber all the time.

80. *The Siphon.*—Bend a tube into the form of the letter U, making one arm somewhat longer than the other; fill it with water, and close both ends with the fingers; then invert it, and place the short end under the surface of water in a vessel. If now both ends be opened, the water will flow out of the vessel through the tube. A bent tube used in this way is called a *siphon*.

To explain the action of a siphon, let us suppose it

filled, and the short arm placed in the water. The pressure then acting on C (Figure 47), and tending to raise the water in the tube, is the atmospheric pressure *less* the weight of the column of water CD. In like manner, the pressure on the end of the tube B is the atmospheric pressure *less* the pressure of the column of water AB. But as this latter column is longer than CD, the force acting at B is less than the force acting at C, and consequently the water will be driven through the tube by *a force equal to the difference of these two forces.* The flow will therefore be the faster, as the difference of level between C and B is greater.

Fig. 47.

81. *Tantalus's Cup.*—This is a glass cup, with a siphon tube passing through the bottom, as shown in Figure 48. If water be poured into the cup, it will rise both inside and outside the siphon until it has reached the top of the tube, when it will begin to flow out. If the water runs into the cup less rapidly than the siphon carries it out, it will sink in the cup until the shorter arm no longer dips into the liquid and the flow from the siphon ceases. The cup will then fill again as before; and so on.

Fig. 48.

In many places there are *springs* which flow at inter-

vals, like the siphon in this experiment, and whose action may be explained in the same way. A cavity under ground may be gradually filled with water by springs, and then emptied through an opening which forms a natural siphon. In some cases of this kind the flow stops and begins again several times in an hour.

82. *The Air-Gun and the Condenser.* — The *expansive force of gases increases when they are compressed.* This is illustrated by the *air-gun*, which consists of a tube, connected by a stop-cock with a small air-tight vessel of very great strength. If a large amount of air be forced into this vessel, and the stop-cock be then opened, the expansive force of the gas will drive a bullet from the tube, as if it were fired from a musket.

The firing of a musket is, in fact, another illustration of the very same kind. When the gunpowder is set on fire, it forms an immense amount of gas, which, being confined in a small space, has a great expansive force, and therefore exerts a great pressure upon the bullet.

An instrument used for compressing air is called a *condenser*. It consists of a strong cylinder, with a piston and valves, arranged precisely as in the force-pump in Figure 44. It works, too, in the same way as the force-pump; the air rushing in through the valve *S* when the piston is raised, and being driven out through the valve *O* when the piston is pushed down. The vessel into which the air is to be forced is screwed to *D*.

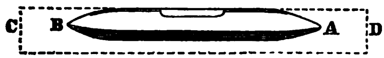
83. *Mariotte's Law.* — The bulk of a gas becomes less just in proportion as the pressure upon it becomes greater; or, in other words, *the volume of a gas is inversely as the pressure which it bears.*

The *elasticity* of a gas becomes greater just in proportion as its bulk becomes less, or as the pressure upon it becomes greater; or, in other words, *the elasticity of a gas is inversely as its volume, and directly as the pres-*

sure which it bears. These facts concerning gases are known as *Mariotte's law*, from their discoverer.

84. *The Spirit Level.* — The *spirit level* (Figure 49) consists of a closed glass tube, *A B*, very slightly curved on the upper side. It is filled with spirit, with the ex-

Fig. 49.



ception of a bubble of air which tends to rise to the highest part of the tube. It is set in a case *C D;* and when it is placed on a perfectly level surface, the bubble is exactly in the middle of the tube, as in the figure.

SUMMARY.

Gases have weight, and, like liquids, press upward, downward, and sideways. (66, 67.)

Gases are acted upon by an expansive force, which is increased by heat and by pressure. (68, 71, 82.)

Bodies are buoyed up in air by a force equal to the weight of the air which they displace. (70.)

The atmospheric pressure balances a column of mercury about thirty inches high, and is equal to about fifteen pounds to the square inch. (73, 74.)

This pressure varies from day to day, and becomes less as the height of the place increases. (75, 76.)

The *barometer* is an instrument for measuring the atmospheric pressure. (77, 78.)

The action of *pumps*, and of the *siphon*, is to be explained by the pressure of the atmosphere. (79, 80.)

The bulk, or volume, of a gas is in the inverse ratio of the pressure which it bears. The elasticity of a gas is in the inverse ratio of its volume, or the direct ratio of the pressure it bears. (83.)

MOTION.

FIRST LAW OF MOTION.

85. *Inertia.*—We know that a stone, or other body, when at rest, will not begin to move of itself, but only on the application of some force; and that, when any body, as a ball, is in motion, it requires some force to stop it.

The inability of a body, whether at rest or in motion, to change its state, is often called *inertia*.

86. *A moving Body, when left to itself, will always move in a straight Line and at the same Rate.*—Mathematicians, from the study of certain motions, have come to the conclusion that a moving body, when left to itself, will always move in a straight line and at the same rate. This is the *first law of motion.*

87. *An unbalanced Force must act upon a Body in order to put it in Motion, or to change the Direction or the Rate of its Motion.*—A ball, held in the hand, remains at rest, because the downward pull of gravity upon the ball is just balanced by the resistance offered by the hand. If the hand is removed so that the force of gravity is unbalanced, then the ball begins to move. If we push with the hands against the opposite sides of a book, the book will remain at rest as long as the push of one hand is just balanced by that of the other. Take away one hand, so that there shall be nothing to balance the push of the other, and the book begins to move. So, in every case, *a body begins to move only when an unbalanced force acts upon it.*

And when a body is once in motion, it *changes the direction and rate of its motion only when an un-*

balanced force is acting upon it. When a body is once in motion, it is just as natural for it to move on in a straight line, with uniform speed, as it is for it to remain at rest when once it is at rest.

88. *The Effect of a Force acting for a Moment only.* —When a body is acted upon by a force only for an instant, as when a ball is struck with a bat, or a bullet is fired from a gun, *it has its greatest speed at first, and its motion is gradually wasted by the resistance it meets* in passing through the air or over the earth.

89. *The Effect of a Force acting continuously.*— When a body is acted upon continuously by a force, as in the case of a railway train, or a steamboat, *the motion, slow at first, gradually increases till it reaches a certain point, when the speed remains unchanged so long as the moving force is unchanged.* When the moving force is increased, the speed increases; and, when it is diminished, the speed diminishes.

90. *The Resistance a moving Body meets increases as the Square of its Velocity.*—The steamboat, in moving, has to push aside a certain amount of water in a second, and this is the chief resistance it meets. Now, as the speed of the boat increases, more water must be pushed aside in a second, and each particle of water must be moved aside more quickly. Hence, the faster it moves, the greater the resistance. Suppose the speed of the boat to be doubled, twice as many particles of water must be pushed aside in a second, and each particle must be pushed aside in half the time. Hence, the resistance becomes fourfold when the velocity is doubled. The resistance, then, *increases as the square of the velocity.*

91. *A moving Body may be in Equilibrium.*—A body at rest is in equilibrium, because the forces acting upon it are balanced. When a train of cars is starting,

the force of the steam is not wholly balanced by the resistance; hence it imparts motion to the train. But as the speed of the train increases, the resistance also increases, until it finally equals the force of the steam. All the force of the steam is now used in balancing the resistance, and the speed no longer changes. Since the two forces acting upon the moving body balance each other, it must be in equilibrium. *Every body moving in a straight line, and with uniform speed, is in equilibrium.*

SECOND LAW OF MOTION.

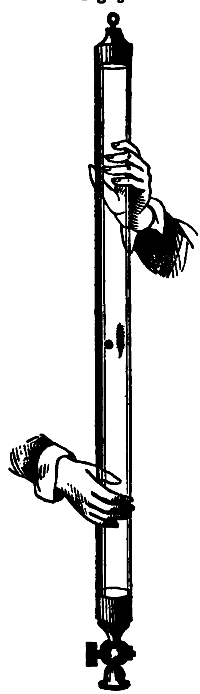
92. *A Force has the same Effect in producing Motion, whether it acts upon a Body at Rest or in Motion, and whether it acts alone or with other Forces.*— When a ball is thrown horizontally, two forces act upon it, one to throw it forward in a straight line, and the other to draw it to the earth in a straight line; and it is found that *it is drawn just as far towards the earth in a given time as a ball that is let fall from a state of rest.* The same is true, in whatever direction the ball may be thrown.

For example, if the force used would send the ball forward 30 feet in a second, and if gravity will pull it from a state of rest 16 feet towards the earth in the same time, the ball at the end of the second will be just 16 feet *below the point it would have reached* had not the force of gravity acted upon it. So, were a ball thrown directly upward with a velocity of 100 feet a second, at the end of the second it would be only 84 feet high; that is, 16 feet *below the point it would have reached* had not the force of gravity acted upon it. If it were thrown directly downward from the top of a high tower with the same velocity, it would be at the end of

116 feet below the top of the tower; that is, 16 *w the point it would have reached* had not acted upon it. Now 16 feet is just the distance case that gravity *would have pulled the ball in l from a state of rest.*

., if the current in a stream is strong enough to boat down stream one mile in an hour, and rson attempts to row the boat directly across am at a rate which would take him across in ·, at the end of the hour the boat will be at osite bank just a mile down stream.

Fig. 50.



. *Body thrown horizontally or y, when acted upon by Grav- ribes a curved Path.*—When *forces* acting upon the body *tantaneous*, it *moves in a line;* when *one is instan- , and the other continuous*, as ase of gravity acting on a ball horizontally or obliquely, *the curved.* Hence a cannon- cribes a curved path; if fired tant object, it must be aimed .

ll Bodies would fall at the te, were it not for the Resist- the Air.—As we see bodies, d heavy, falling through the come to think that the force ty causes heavy bodies to fall pidly than light ones; but if we coin and a feather in a long be and exhaust the air com- (Figure 50), the two bodies through the tube in the same time. It must,

then, be the resistance of the air which causes a lighter body to fall more slowly through the atmosphere than a heavy one does.

When the force of gravity is unimpeded in its action, *it will cause every body, whatever may be its size, shape, or density, to fall with exactly the same speed.*

95. *When a Body is moving directly downward, Gravity increases its Velocity at the Rate of 32 Feet a Second.* — A body falls 16 feet the first second, and acquires a velocity of 32 feet during the time. As gravity has the same effect upon a moving body as upon one at rest, a falling body will gain in velocity 32 feet each second. When therefore a body is moving directly downward, gravity increases its velocity at the rate of 32 feet a second.

96. *How to find the Distance a Body falls in a given Time.* — The distance a body falls the first second, or 16 feet, is exactly *the mean between* 0, *its velocity at starting, and* 32, *its velocity at the end of the second.* As it would gain a velocity of 32 feet during the next second, it would have a velocity of 64 feet at the end of that second. The velocity it has already acquired would cause it to fall 32 feet the second second, and the force of gravity acting upon it during that time would cause it to fall 16 feet more; hence it would fall 48 feet during the second second. It will be noticed that 48 is just the mean of 32, its velocity at the beginning of the second, and 64, its velocity at the end of the second.

During the first two seconds, the body would fall $48 + 16 = 64$ feet. This is just twice the mean of 0 and 64. Hence, *to find the distance that any body would fall when acted upon by gravity alone during any number of seconds, find its mean velocity during the time, and multiply it by the number of seconds.*

To find the velocity of a falling body at the end of

any second, multiply 32 *feet by the number of seconds it has been falling.*

97. *When a Body is moving directly upward, Gravity retards its Velocity at the Rate of* 32 *Feet a Second.* —We know that gravity has the same effect on a body in motion as on one at rest (92). Since, then, it causes a body in falling from a state of rest to *acquire a velocity of* 32 *feet a second*, it must, in the case of a body moving directly upward, *diminish its velocity at the rate of* 32 *feet a second.* And it must also *cause it to rise each second* 16 *feet less than if it were not acting upon it.*

98. *How to find the Distance a Body, when thrown upward, will rise in a given Time.* — To find this distance, *take the mean velocity of the body during the time, and multiply it by the number of seconds.* To find the *velocity at any particular second, multiply the number of seconds the body has been rising by* 32, *and subtract this from the velocity the body has at starting.*

THIRD LAW OF MOTION.

99. *Momentum.* — *The product of the velocity of a body multiplied by its mass* is called its *momentum.* By the *mass* of a body, we mean its *quantity of matter.* The same force acting upon bodies containing different quantities of matter does not give each the same velocity; but it does give each the same *momentum*, or *quantity of motion;* that is, *if the quantity of matter in each be multiplied by its velocity, the products will all be equal.*

100. *A moving Body cannot impart Motion to another Body without itself losing the same Quantity of Motion.* — This *third law of motion* results from

the fact that a moving body is unable of itself either to increase or to lessen its quantity of motion. On meeting another body, it may impart some of its own motion to it; but it cannot give motion to this body, and at the same time retain all its own motion.

This is often called the law of *action* and *reaction*, and stated thus: *action and reaction are always equal and in opposite directions*. When any force acts in opposite directions, it is usually said to *act* in one direction, and *react* in the opposite. Thus in firing a cannon, the expansive force of the gases set free by the burning powder acts equally in all directions. It acts upon the sides with equal and opposite forces which neutralize each other unless the cannon bursts. It also acts toward the muzzle and breech with equal forces, which produce equal effects, one upon the ball and the other on the cannon, causing the *recoil*. The ball and the cannon both have the same momentum; but the ball, since it has a much less mass, gets a much greater velocity. This expansive force is said to *act* upon the ball and to *react* upon the *gun*. So, too, in walking, we are said to react upon the earth. The truth is, that the bent leg acts like a bent spring between our bodies and the earth; and when the spring straightens, it pushes us away from the earth and the earth away from us; the earth being moved as much less than our bodies as its mass is greater.

101. *It requires Time to impart Motion to a Body as a Whole.* — The forces which impart motion to a body often act directly upon only a few of its particles. When a ball is struck by a bat, only a small part of it receives the blow, and when a bullet is shot from a gun, the gases (46) act only upon one-half of it. In such cases, it is clear that *the motion must be transmitted from particle to particle*; and *this transmission of*

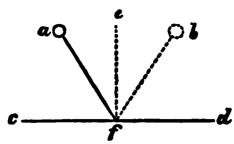
motion from particle to particle requires time, although this time may be exceedingly short. If the force acts so suddenly that there is not time enough for this transmission, the part acted upon is flattened or chipped off. Thus a musket-ball may be fired through a window-pane, making a clear round hole without cracking the glass. If the ball had been thrown by the hand, the whole pane would have been shattered. In the first case, the speed of the ball was so great that the particles in front of it had not time to transmit their motion to those about them; hence they moved on alone, leaving the others at rest. If the pane had been suspended by a fine thread, the ball would have passed through it in the same way, without breaking the thread, or causing the pane to swing in the least. So a door half open may be pierced by a cannon-ball without being shut. The end of a musket in a soldier's hand has been known to be carried away by a cannon-ball without his being aware of it. A tallow candle may be fired through a board, since it gets through it before the parts of the tallow have time to yield. In this way, a soft missile may hit as hard as lead, if fired with sufficient speed.

We see, then, that when a moving body meets with another it seldom expends all its power in imparting motion to that body as a whole, but also *pierces* it more or less. The power of a body to pierce another *increases as the square root of its velocity;* that is, if a body is to pierce another twice as far, it must have four times the velocity; if three times as far, nine times the velocity; and so on.

102. *Reflected Motion.*— When an elastic ball is thrown against the floor, it rebounds. If it is thrown directly downward, it retraces its path in its rebound. If it is thrown obliquely, it rebounds obliquely in an

opposite direction. In Figure 51, if the ball is thrown in the direction *a f*, it will rebound in the direction *f b*. If the line *e f* be drawn at right angles to the surface, the angle formed by the two lines *a f* and *e f* is called the ***angle of incidence***, and is always equal to the angle formed by the two lines *b f* and *e f*. This last angle is called the ***angle of reflection***. In reflected motion, ***the angle of incidence always equals the angle of reflection***.

Fig. 51.



SUMMARY.

The inability of a body, whether at rest or in motion, to change its state, is called *inertia*. (85.)

A moving body, when left to itself, will always move in a straight line and at the same rate. (86.)

An unbalanced force must act upon a body in order to put it in motion, or to change the direction or rate of its motion. (87.)

When a force acts upon a body for a moment only, the motion which it imparts is gradually wasted away, owing to the resistance which the body meets. (88.)

The resistance which a moving body meets increases as the square of the velocity of its motion. (90.)

A body moving in a straight line and with uniform velocity is in *equilibrium*. (91.)

An unbalanced force has the same effect, whether it act upon a body at rest or in motion, and whether it act alone or with other forces. (92.)

A body thrown horizontally or obliquely, when acted upon by gravity, is made to move in a curved path. (93.)

Were it not for the air, a light body would fall as fast as a heavy one. (94.)

Gravity acting alone causes a body to fall from a state of rest about 16 feet in a second. When a body is moving directly downward, gravity increases its velocity at the rate of 32 feet a second. When a body is moving directly upward, gravity retards its velocity at the rate of 32 feet a second. (95, 97.)

The same force always gives to a body the same quantity of motion, or *momentum*. The momentum of a body is found by multiplying its weight by its velocity. (99.)

A moving body cannot impart motion to another body without itself losing the same quantity of motion. (100.)

When the same force acts in opposite directions, it is often said to *act* in one direction and to *react* in the opposite. (100.)

It takes time to give motion to a body as a whole. (101.)

In reflected motion, the angle of incidence equals the angle of reflection. (102.)

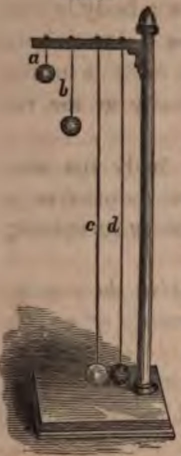
☞ For *Problems* under the Laws of Motion, see Appendix.

THE PENDULUM.

103. *A Pendulum is a heavy Body hung from a fixed Point by means of a Cord or Rod.*—When the centre of gravity of the body is directly under the point of support, the body remains at rest; but if the body be drawn out of this position and let go, it will fall towards a vertical line passing through the point of support; and when it has reached this line, it will, owing to its inertia, pass beyond it. On coming to rest, it again falls toward

this vertical line and again passes beyond, and thus continues to swing from side to side.

Fig. 52.



104. *First Law of the Vibration of the Pendulum.* — Suppose *d*, in Figure 52, to be a leaden ball hanging by a fine silk thread. Pull it to one side so that it shall swing through a very short arc, and count the number of its vibrations in a minute. Now bring it to rest again, and draw it to one side so that it shall swing through a little longer arc, and again count its vibrations in a minute. Again bring the ball to rest, then cause it to swing through an arc yet longer, and count the vibrations in a minute. In all three cases, the number of vibrations in a minute will be equal.

By a *vibration* is meant the whole of the pendulum's movement *in one direction. The arc through which the pendulum swings* is called the *amplitude* of its vibration.

*When the length of the pendulum remains the same, the pendulum always vibrates in nearly the same time, whatever be the amplitude of the vibration.**

This singular property of the pendulum is called *isochronism*, from two Greek words, signifying *equal times*, and the vibrations of the pendulum are said to be *isochronous*.

105. *The Second Law of the Vibration of the Pendulum.* — Let *d* and *c*, in Figure 52, be two pendulums exactly alike, except that the ball of one is lead, and of the other ivory. It will be found that, making allowance

* If the amplitude does not exceed 3°, the time of vibration will always be *exactly* the same.

r the resistance of the air, each performs the same mber of vibrations in the same time. *For pendulums the same length, the time of the vibration is the me, whatever the pendulum may be made of.*

106. *Third Law of the Vibration of the Pendulum.* Let b, in Figure 52, be a pendulum one-fourth the gth of c, and a another, one-ninth the length of c. will be found that b vibrates twice as fast as c, and a ee times as fast as c. This shows that, *for pendu- ns of unequal length, the time of the vibration is oportional to the square root of the length;* that is, lengths of the pendulum being made 4, 9, and 16 es greater, the times of vibration will be only 2, 3, d 4 times longer.

107. *Fourth Law of the Vibration of the Pendulum.* It is found that when a pendulum of a given length placed on different parts of the earth's surface, the e of the vibrations is not always the same. Towards poles it is found to vibrate more rapidly than at the ator. Mathematicians have shown that this is be- se the force of gravity is stronger at the poles. They ve shown that, *in different parts of the earth, the e of vibration for pendulums of the same length is the inverse ratio of the square root of the intensity gravity;* that is, if the intensity of gravity were four es as great in one place as in another, the time of ration for a pendulum of the same length would half as great, and so on.

108. *The Use of the Pendulum for Measuring Time.* The most important use of the pendulum is for asuring time. The common *clock* is merely *a con- vance for recording the beats of the pendulum, and eping up its motion.* The essential parts of such a ck are shown in Figure 53. The toothed wheel R, lled the *scape-wheel*, is turned by a weight or spring,

Fig. 53.

and its motion is regulated by
escapement *n* *m*, which swing
the axis *o*; the vibrations of the
dulum being communicated to
means of the forked arm *a b*.
the pendulum is at rest, one of th
of the scape-wheel rests upon the
side of the hook *m*, and the cloc
not go. If now the pendulum be
motion, so that the hook *m* is
from the wheel, the tooth which
on it is set free, and the wheel be
turn; but it is soon stopped by th
n, which moves up to the whee
moves away from it, and catche
under side the tooth next belo
the pendulum swings back, the
moves away, the wheel again b
turn, but is stopped again on th
site side by the hook *m*, which
the tooth next to the one it held
and thus each vibration of the pe
allows the scape-wheel to move forward through
equal to one-half of one of its teeth. If, then, th
has thirty teeth, it will turn round once in sixty
the pendulum. Upon the axis of this wheel the
hand of the clock is placed. It is connected with
wheel, which takes sixty times as long to revol
which carries the minute-hand; and this latter
is connected with another, which turns in twelv
the period, and carries the hour-hand. Thus the
hand registers the pendulum-beats up to sixty,
minute; the minute-hand registers the revolutions
second-hand up to sixty, or one hour; and the hou
those of the minute-hand up to twelve, or half a c

'ere it not for the pendulum and escapement, these
els would be whirled round very fast by the action
ie weight or spring, and the clock would soon *run*
n. On the other hand, were there not some means
eping up the motion of the pendulum, it would soon
rought to rest by the resistance of the air and the
on at the point of suspension. Its motion is kept
y means of the escapement, which is so constructed
give it a slight push at each vibration. The ends
ie two hooks have inclined surfaces against which
tooth of the wheel, as it leaves them, presses with
iderable force, so as to throw the escapement for-
l a little. This impulse is communicated, through
axis *o*, and the arm *a b*, to the pendulum.

SUMMARY.

pendulum is a heavy body hung from a fixed point
neans of a cord or rod. (103.)

he laws of the pendulum are four: —

t, When the length of the pendulum remains the
e, the pendulum vibrates in nearly the same time,
tever be the amplitude of the vibration. (104.)

l, For pendulums of the same length, the time of
vibrations is the same, whatever the pendulum may
nade of. (105.)

l, For pendulums of different lengths, at the same
e, the time of the vibrations is proportional to the
re root of the lengths. (106.)

h, In different parts of the earth, the time of the
ations for pendulums of the same length is in
inverse ratio of the square root of the intensity of
vity. (107.)

he pendulum is used for measuring time. (108.)

MACHINES.

THE LEVER.

109. *There are three Kinds of Lever.* — When a workman wishes to raise a large stone, he places an iron bar under it, as in Figure 54, with a block under the bar near the stone, and then presses down upon the other end of the bar; or else he places the end of the bar under the stone, as in Figure 55, so that one end of it rests upon the ground, and then lifts upon the other end. The bar thus used constitutes one of the *simple machines.* It is called the *lever. The mass to be raised* is called the *weight. The moving force* applied at the other end of the bar is called the *power;* and *the point on which the bar rests* is called the *fulcrum. The parts between the fulcrum and the points where the power and weight act* are the *arms* of the lever. In the first case, the fulcrum was between the weight and the power; in the second case, the weight was between the fulcrum and the power. In the fishing-rod (Figure 56), one hand, *f*, is the fulcrum; the other hand, *P*, is the power; and the fish is the weight. Here the power is applied between the fulcrum and the weight.

Fig. 54.

Fig. 55.

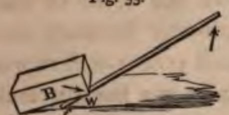
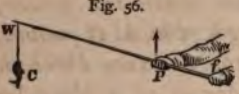


Fig. 56.



There are, then, three kinds of lever: —

(1) That *with the fulcrum between the weight and power.*

(2) That *with the weight between the fulcrum and power.*

(3) That *with the power between the fulcrum and the weight.*

These three kinds of lever are shown in Figure 57.

Fig. 57.

110. *The Law of the Lever.*—In the lever of the first kind, if the fulcrum is just half-way between the weight and power, then the weight and power will move through equal distances. In this case, the weight and power must be equal in order to balance each other, or to be in equilibrium. If the power were twice as far from the fulcrum as the weight, then the weight would move through only half the distance that the power does, and in this case the power need be only half the weight in order to balance it.

Thus we see that, in the case of the lever, *the weight and power will balance each other when the power, multiplied by the distance through which it moves, equals the weight multiplied by the distance through which it moves;* that is, if the fulcrum of a lever be so placed that one end of the lever will move through a thousand inches while the other end moves one inch, then a power of one pound on the former will balance a weight of a thousand pounds on the latter.

111. *The Law of Machines in General.*—The same

is found to be true in the case of every machine, however complicated; namely, that *the power and weight will balance each other when the power, multiplied by the distance through which it moves, equals the weight multiplied by the distance through which it moves.*

There is *no real gain of mechanical force* in a lever or a machine of any kind. A machine is only *an arrangement by which a small force acting through a great distance is converted into a great force acting through a small distance, or else a great force acting through a small distance is converted into a small force acting through a great distance.*

When a small force, by acting through a great distance, is made to raise a great weight, or do a great deal of work, there is said to be a gain of power in the machine. When, on the contrary, a great force, in moving through a small distance, lifts only a small weight, or does very little work, there is said to be a loss of power in the machine. But *whenever there is a gain in power, there is a corresponding loss in speed;* and *whenever there is a loss in power, there is a corresponding gain in speed.* For if, in the machine, a power of one pound is made to move a weight of ten pounds, then the weight moves only one-tenth as fast as the power. But when a power of ten pounds is made to move a weight of one pound, then the weight moves ten times as fast as the power.

112. *Gain and Loss of Power in the Lever.*—In a lever of the *first* kind, *when the fulcrum is just halfway between the weight and power*, there is *neither gain nor loss in power. If the fulcrum is nearer the weight than the power*, there is *a gain in power and a loss in speed. If the fulcrum is nearer the power than the weight*, there is *loss in power and gain in speed.*

In a lever of the *second* kind, *the power is always farther from the fulcrum than the weight*, and consequently it always moves through greater distance. Hence, in this kind of lever, *there is always a gain in power and a loss in speed.*

In a lever of the *third* kind, *the weight is always farther from the fulcrum than the power*, and must move the greater distance. In this kind of lever, then, *there is always a loss in power and a gain in speed.*

113. *The Compound Lever.*—Sometimes two or more simple levers are combined, as shown in Figure 58.

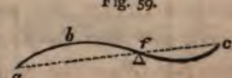
Fig. 58.

Suppose that P be five times as far from the fulcrum f as A is, the point P will then move five times as fast as the point A, and a pull of one pound on P will exert a pull of five pounds on A. If B is five times as far from the fulcrum F as W is, the five pounds of pull on B will exert twenty-five pounds of pull at W. In this case, one pound of pull exerted at P will balance twenty-five pounds at W. But it will be found on trial that by pulling P down one inch, W will be raised only one twenty-fifth of an inch.

Such a *combination of levers* is called a *compound lever.*

114. *Bent Levers.* — Sometimes the arms of the lever are bent, as shown in Figure 59. In such a lever, the lengths of the arms are *straight lines drawn from the fulcrum at right angles to the lines which show the direction in which the power and weight act.*

Fig. 59.

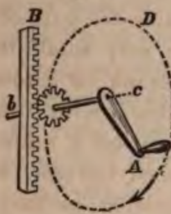


The common claw-hammer, as used for drawing nails, is an illustration of this kind of lever.

THE WHEEL AND AXLE.

115. *The Rack and Pinion.* — In Figure 60, we have a machine called the *rack and pinion*. The *crank A* turns a small toothed wheel called the *pinion*. The teeth of the pinion, one after another, catch under the teeth of an upright bar *B*, called the *rack*, and each tooth raises the bar a little. If the rack is placed under the weight, it will carry up the weight as it rises.

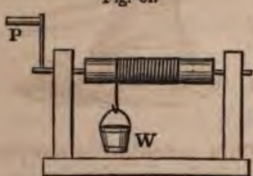
Fig. 60.



116. *The Rack and Pinion is a Modification of the Lever.* — In the rack and pinion, the *crank* takes the place of the *long arm* of the lever; the rod, or *axle*, upon which the pinion turns takes the place of the *fulcrum;* and the *pinion* takes the place of the *short arm*. Each tooth of the pinion is, in fact, the short arm of a lever, and *the pinion is a contrivance by which the lever is furnished with several short arms instead of one.* These short arms act upon the weight one after another, so that it can be raised a considerable distance without interruption. With the simple lever, it is evident that a weight can be lifted but a little way at a time.

117. *The Windlass.* — In the *windlass* (Figure 61), a thick axle, or *barrel*, takes the place of the *pinion*, and a *rope* that of the *rack*. When the crank is turned, the rope is wound upon the barrel, and the weight raised. In one turn of the crank, the rope is wound once round the barrel, and the weight is raised a distance equal to the circumference of the barrel; while the

Fig. 61.



power at the end of the crank moves through a path like the dotted line in Figure 60. If the power moves ten times the distance the weight moves in the same time, a power of one pound at the end of the crank ought to balance ten pounds of weight hung from the barrel (111).

118. *The Capstan.*—In the windlass, the longer the crank and the smaller the barrel, the greater the gain of power. If, however, the barrel be made very small, it will not be strong enough; while if the crank be made very long, it cannot be conveniently turned with the hand. But instead of one crank there may be a number of spokes; and, if the barrel be placed upright, a man may pull upon one spoke after another as they come within his reach, and thus turn the barrel, or several men may walk round it, pushing against the spokes. Such *an upright windlass, with long spokes*, is called a *capstan*, and is much used on board ships.

Sometimes the capstan (Figure 62) is arranged with a single long arm, to which a horse can be harnessed.

Fig. 62.

119. *The Wheel and Axle.*—This machine is simply *a wheel with a thick axle*, like the barrel of the wind-

Fig. 63.

lass. The wheel takes the place of the crank of the windlass, or the spokes of the capstan. Power is applied to the wheel, either by means of pegs upon its rim, as in Figure 63, or by means of a rope or band, as in Figure 64.

Suppose that the circumference of the wheel is eight times that of the axle. If we hang a weight of one pound to the wheel, we must hang a weight of eight pounds to the axle in order to balance it; and the former will move eight inches, while the latter moves one (111).

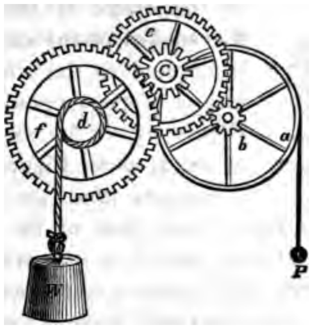
120. *The Ratchet.* — The *ratchet* is *an arrangement to keep the wheel from turning except in one direction.* It consists of a catch *c* (Figure 64), which plays into the teeth of the wheel *A B*. It thus allows the wheel to turn to the left, but keeps the weight from pulling it back towards the right.

Fig. 64.

121. *Wheel-work.* — In the wheel and axle, the larger the wheel and the smaller the axle, the greater the gain of power. But, as has already been said (118), if the barrel be made very small, it may not be strong enough; and, on the other hand, if the wheel be made very large, it will be too heavy and take up too much room. Instead of using such a large wheel, we may have *several wheels and axles acting upon one another*, like the levers in the compound lever (113). Such a combination, or *train*, of wheels and axles is often called *wheel-work.* The power is applied to the circumference of the first wheel, and the weight is hung to the axle of the last wheel.

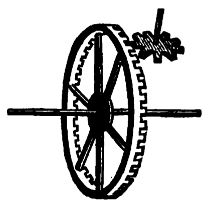
Sometimes one wheel turns the other by rubbing

Fig. 65.



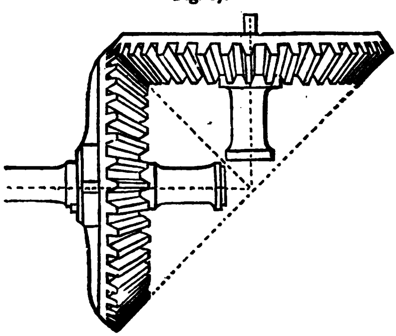
against it, or by *friction*. The most common way, however, is by means of *teeth* or *cogs* on the surfaces of the wheels and axles, as shown in Figure 65.

Fig. 66.



If the teeth project from the *side* of the wheel, as in Figure 66, it is called a *crown-wheel*. If their *edges are sloped*, as in Figure 67, the wheel is called a *bevel-wheel*. Again, the wheels and axles may be made to act upon one another by means of a *belt*, or band, passing over them both.

Fig. 67.



They may thus be at any distance apart, and ma either the same way or contrary ways, according belt does or does not *cross* between them.

THE PULLEY.

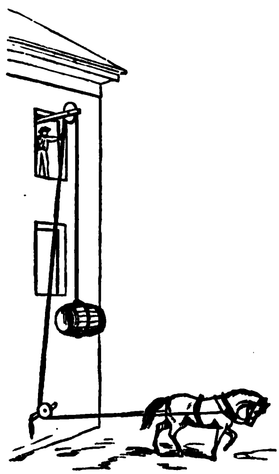
122. In Figure 68, we have a fixed ring through passes a cord with a weight hung to it. By p *down* the cord at *P*, the weight is drawn *up*. It is desirable thus to *change the direction* of the powe

Fig. 68.

If we use a ring for this purpose, m the power will be wasted by the *fricti* rubbing, of the rope against the ring. may get rid of much of this friction by instead of the ring, a *pulley*. This is *a wheel with a grooved rim* to keep th in place.

There would be no gain in power by the use

Fig. 69.



pulley. It is evident that one pound on one side of the wheel would balance just one pound on the other side; and that if the former were drawn down one inch, the latter would be drawn up just one inch.

A very common use of the pulley in *changing the direction* of the power is illustrated in Figure 69.

123. *Fixed and Movable Pulleys.* — In Figure 70, the frame of the pulley $D\,C$ is fastened to the ceiling; the frame of the pulley $A\,B$ rises as the rope P is drawn down. A pulley like $D\,C$ is called a *fixed* pulley; one like $A\,B$, a *movable* pulley. The *frame of the pulley* is often called the *block.*

Fig. 70.

124. *The Law of the Pulley.* — In the combination, or *system*, of pulleys in Figure 70, it is evident that the rope must have the same *tension*, or *strain upon it*, from one end to the other. This fact, namely, that *a cord when stretched must have the same strain upon it throughout its length*, is called the *law* of the pulley.

125. *Systems of Pulleys with one Rope.* — In Figure 70, the tension or strain of the rope is equal to the power P, since it balances the power. If a weight of one pound is hung to the rope at P, there will be a strain of one pound on the part of the rope on that side of the pulley. There must then be a strain of one pound upon the part of the rope between A and D, and a strain of one pound between B and H. These two tensions, $A\,D$ and $B\,H$, will evidently sustain a weight of two pounds at W. In this system of pulleys, then, a power of one pound balances a weight of two pounds.

But here, as in every other machine (111), *what is gained in power is lost in speed.* If the power P is drawn down one foot, the weight W will rise only half a foot; for of the one foot added to the length of

CP, one-half will be taken from AD and one-half from BH.

In the system of pulleys shown in Figure 71, we see that one pound at P will balance three pounds at W,

Fig. 71.

Fig. 72.

since each of the three parts of the rope on that side of the pulley C has a tension of one pound. But P must be drawn down three feet in order to raise W one foot.

In Figure 72, we have a system of pulleys in which the weight is four times the power; and in this case the power evidently moves four times as far as the weight.

126. *Systems of Pulleys with more than one Rope.*—Figure 73 represents a system of pulleys, in which two ropes are used. Here a weight of four pounds is balanced by a power of one pound. The parts of the rope AD and AB must each have a tension equal to the power. The rope ACB balances the two tensions, BP and BA, and must therefore have a tension of twice the power. The three tensions supporting the pulley A amount therefore to four times the power.

the system shown in Figure 74, four ropes are used. tensions of the several ropes will be readily under-

Fig. 73.

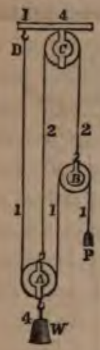


Fig. 74.

stood from the numbers. In this case, *the power is doubled by each movable pulley* which is added.

THE INCLINED PLANE.

127. When a heavy cask is to be raised into a cart or dray, a ladder is often used. One end of the ladder is placed upon the cart behind and the other end upon the ground, and the cask is rolled up the inclined surface thus formed. One man may thus raise a load of several hundred weight with comparative ease. *An inclined surface* used in this way is called an *inclined plane*.

We often see inclined planes on a large scale in *roads*.

128. *The Law of the Inclined Plane the same as that of other Machines.*— In Figure 75, we have an inclined plane. *W* is the weight, which is balanced by the power *P*. *B C* is the *height* of the inclined

Fig. 75.

plane, and $A\ C$ is its *length*. It is evident that the power must descend a distance equal to the length of the inclined plane, in order to raise the weight a distance equal to its height. Now it is found on trial that, if the length of the inclined plane is sixteen feet, and its height four feet, a power of one pound will balance four pounds of weight. But one multiplied by sixteen equals four multiplied by four; that is, *the power multiplied by the distance through which it acts equals the weight multiplied by the distance through which it is raised.* It follows from the above, that *the greater the length of the inclined plane, compared with its height, the less the force necessary to raise a weight, and the slower the weight rises.*

THE WEDGE.

129. Instead of lifting a weight by moving it along an inclined plane, we may do the same thing by *pushing the inclined plane under the weight.* When thus used, the *movable inclined plane* is called the *wedge.* A wedge which is used for splitting wood has usually the form of a double inclined plane, as in Figure 76. *The law of the wedge is the same as that of the inclined plane;* but since a wedge is usually driven by a *blow* instead of a force acting continuously, it is difficult to illustrate this law by experiments.

Fig. 76.

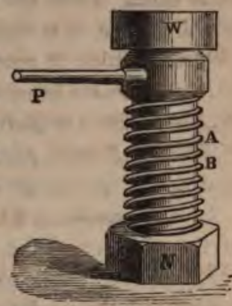
130. *Uses of the Wedge.* — The wedge is especially useful *when a large weight is to be raised through a very short distance.* Thus a tall chimney, the foundation of which has settled on one side, has been made upright again by driving wedges under that side. So, too, ships are often raised in docks by driving wedges under

their keels. *Cutting and piercing instruments*, such as razors, knives, chisels, awls, pins, needles, and the like, are different *forms of wedges*.

THE SCREW.

131. The *screw* (Figure 77) is *a movable inclined plane, in which the inclined surface winds round a cylinder*. The cylinder is the *body* of the screw, and the inclined surface is its *thread*.

Fig. 77.



The screw usually turns in a block *N*, called the *nut*. Within the nut there are threads exactly corresponding to those on the screw. The threads of the screw move between those of the nut.

The power is usually applied by means of a lever *P*. Sometimes the screw is fixed and the nut is movable, and sometimes the nut is fixed and the screw movable.

132. *The Endless Screw.* — In Figure 78, the thread of the screw works between the teeth of the wheel, and turns it. Since as fast as the teeth at the left escape from the screw those on the right come up to it, the screw acts on the wheel continually; hence the name of the machine.

Fig. 78.

SUMMARY.

A *machine* is a contrivance by which force is made to do work. In a machine there is no real gain of force, but a force may be changed in direction, and a small force

acting through a great distance may be conve
large force acting through a small distance,
force acting through a small distance convert
small force acting through a great distance. (1

The first simple machine is the *lever*. There
kinds of levers, depending upon the relative po
the *weight*, the *fulcrum*, and the *power*. (109.)

In every machine, the power and weight will
each other when the power multiplied by the d
which it moves is equal to the weight multiplied
distance which it moves in the same time. (111.)

A *compound lever* is a machine in which two or
simple levers are combined. (113.)

The *rack and pinion* is a lever whose short ar
multiplied in the pinion. (116.)

In the *windlass*, the barrel and the rope take the pl
of the pinion and the rack. (117.)

In the *wheel and axle*, the long arm of the lever is mu
tiplied as well as the short one. (119.)

Several wheels are often combined so as to act upon
one another. The wheels may be made to act upon one
another by means of *cogs*, or by means of *belts*. (121.)

The direction in which a force acts may be changed by
means of a single fixed *pulley*. (122.)

In a system of pulleys, the mechanical advantage depends upon the fact that *a stretched rope will have the same tension throughout its whole length*. (124.)

The fourth simple machine is the *inclined plane*. (127.)

The fifth simple machine is the *wedge*. This is really a movable inclined plane which is pushed under the weight to be raised. (129.)

The sixth simple machine is the *screw*. This is also a movable inclined plane arranged round a cylinder. (131.)

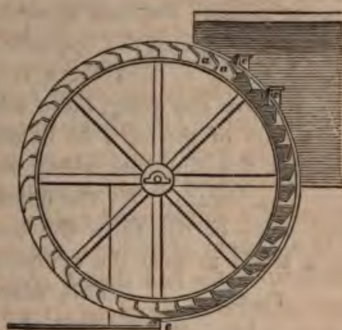
WATER POWER.

133. *Water Wheels.* — An important source of mechanical power is *falling water.* The falling or running water is made to turn a wheel, called a *water wheel*, and this wheel is made to drive machinery.

Water wheels are of various forms. Some turn *on an upright axis*, and others *on a horizontal axis.* The latter are called *vertical water wheels ;* and the former, *horizontal water wheels.*

134. *Vertical Water Wheels.* — One of the most common forms of vertical water wheels is the *breast-wheel*, represented in Figure 79. It consists of a series of boxes, or *buckets*, arranged on the outside of a wheel or cylinder. Water is allowed to flow into these buckets on one side of the wheel, and by its weight causes the wheel to turn. The buckets are so constructed that they hold the water as long as possible while they are going down, but allow it all to run out before they begin to rise on the other side.

Fig. 79.



The *overshot* wheel is similar to the breast-wheel in all respects, except that the water is led over the top of the wheel and poured into the buckets on the other side.

The *undershot* wheel has boards projecting from its circumference, like the paddle-wheel of a steamboat. The water runs under the wheel, and turns it by the force of the current pressing against the boards.

135. *Barker's Mill.* — In Figure 80, we have a hollow upright cylinder, with two horizontal arms at the bottom, and turning on an axis. The cylinder is open at the top, but closed below, except that it has two holes on opposite sides of the arms near the end, as shown in the figure. If water be poured in at the top, the cylinder begins to turn round, and will continue to turn as long as the supply of water is kept up. If the holes in the arms are stopped up, the cylinder ceases to move. This apparatus is known as *Barker's mill.* Its action is easily understood when we recollect that *liquids press equally in all directions* (56). If the holes in the arms are plugged up, the water presses forward against the plug; and it presses backward against the opposite part of the arm with an equal force, so that there will be no motion. If now we remove the plug, there will be no pressure against that part of the arm to balance the backward pressure against the opposite side; and the arm consequently turns backward. As the holes in the arms are on opposite sides of the tube, the backward pressure on each arm tends to turn the cylinder in the same direction.

Fig. 80.

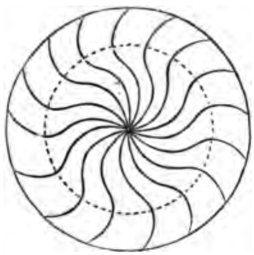
This machine gains in power by curving the arms, as shown in Figure 81; for the water is thus made to press more powerfully against the bend of the arm as it flows through the tube.

Fig. 81.

136. *The Turbine Wheel.* — The power of Barker's mill, as represented in Figure 81, would evidently be increased by increasing the number of the arms. Instead of these arms we might have curved partitions

placed between two flat disks, forming a wheel, as shown in Figure 82.

Fig. 82.



Suppose now that the wheel were cut round where the dotted circle is seen in the figure, and that the outer part were arranged to turn round freely while the central part was kept stationary. If water were poured into the wheel from above, the outer part would of course turn round just as the whole wheel did before it was cut. For the action of the water against the partitions would evidently be the same as before, and it was this action which turned the wheel.

The arrangement just described is that of the *turbine wheel*, the most efficient water wheel ever invented.

STEAM POWER.

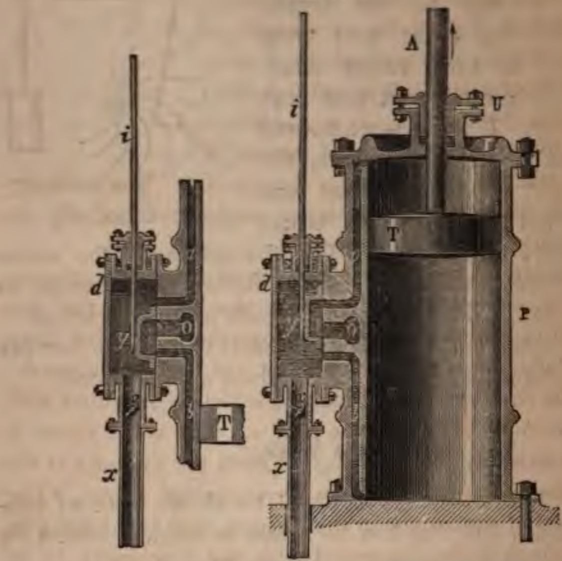
137. *The Steam Engine.*—The elastic force of confined steam (71, 82) can be made to work a piston by the arrangement shown in Figure 83.

The steam coming from the boiler by the tube *x* passes into the box *d*. From this box extend two pipes, *a* and *b*, for carrying the steam, one above and the other below, the piston. A sliding valve *y* is so arranged that it always closes one of these pipes. In the right-hand figure, the lower pipe *b* is open, and the steam can pass in under the piston and force it up. At the same time, the steam which has done its work on the other side of the piston passes out from the cylinder through the pipes *a* and *O*.

The sliding valve is connected by means of the rod *i* with the crank of the engine, so that it moves up and

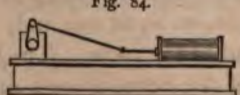
down as the piston moves down and up. As soon, the as the piston has reached the top of the cylinder, t sliding valve is brought into the position shown in t

Fig. 83.



left-hand figure. The steam now passes into the cyli above the piston through the pipe *a* and forces the p down, and the steam on the other side which has its work goes out through *b* and *O*. The sliding is now again in the position shown in the right- figure, and the piston is driven up again as before; thus it keeps on moving up and down, or in and This kind of motion is called *reciprocating* motion.

Fig. 84.



In using the engine for c work, it is generally necessa change this reciprocating m into a *rotary* one; that is

make the piston, as it moves up and down, ***turn a wheel***. This is usually done by means of a ***crank***. The crank is sometimes connected with the piston-rod directly, the cylinder being placed either horizontally, as shown in Figure 84, or upright, as in the engine represented in Figure 86. In other cases, the piston-rod turns the crank by means of a *walking-beam*, the arrangement and action of which will be evident from Figure 85. The walking-beam is much used for large engines, especially on steamboats.

Fig. 85.

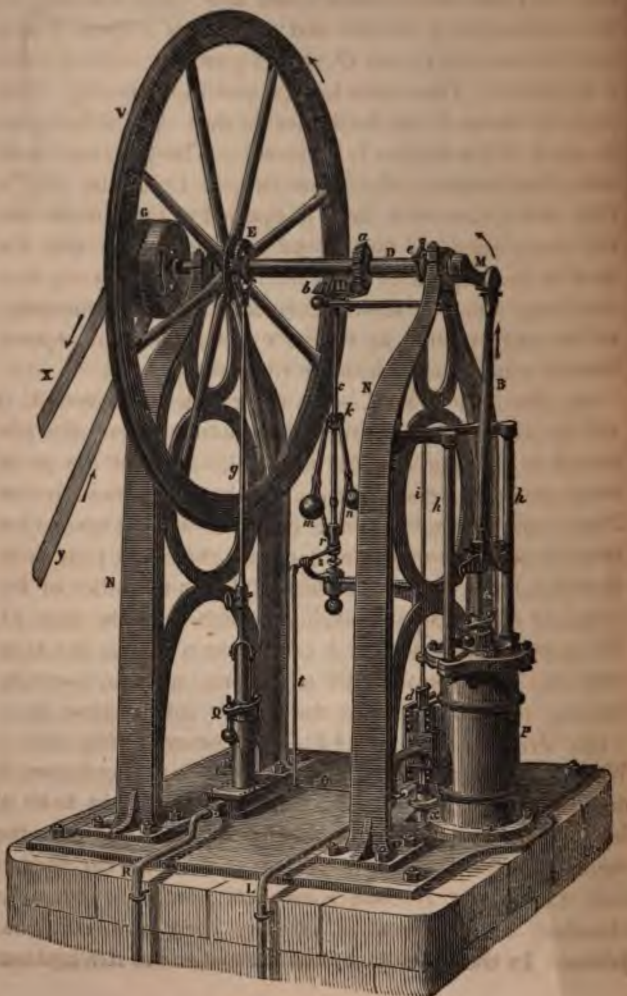
In Figure 86, we have a picture of a small stationary steam-engine, which shows how the parts of the machine already described are put together, and also illustrates those parts which have not yet been mentioned.

On the right is the cylinder *P*, which is supplied with steam from the boiler by the pipe *x*. The waste steam is carried away by the pipe *L*. Within the cylinder is the piston moving up and down as explained above. The piston-rod *A* moves the crank *M*, and thus turns the axle *D*, which may be connected with the machinery to be driven, by means of a belt *X*, as here, or by a train of wheels, or in various other ways. *Q* is a pump, like that shown in Figure 45, which supplies the boiler with water, through the pipe *R*. It is worked by the engine itself by means of the rod *g* and the *cam*, or *eccentric*, *E*.

138. *The Governor.*—The *governor* is a contrivance by which the engine regulates its own speed, so that it may not be too suddenly quickened or retarded by variations in the work to be done. It consists of two arms, *k r* (Figure 86), carrying heavy iron balls, *m*, *n*, at one end, and attached by joints at the other end to the rod *c*. The whole is made to rotate by means of the bevel-wheels *a*

and b (121), which are turned by the engine itself. If the speed of the engine is quickened, the governor rotates

Fig. 86.



, and the arms and balls tend to separate more and ; just as two balls hung side by side will do when trings by which they are held are twirled by the . As the arms spread out, they raise the ring *r*, h slides freely on the rod *c;* and as *r* rises, it acts the levers *s*, *t*, and *O*, which partially close a valve e pipe *x*. This valve is seen at *v* in Figure 83. The ly of steam from the boiler is thus diminished, and peed of the engine is retarded. The governor now es less rapidly, the arms drop a little, the ring *r* s down, the valve in *x* is opened a little more, let- steam pass to the cylinder more freely, and the d of the engine is quickened again. Thus any ten- y to go faster or slower corrects itself very promptly; the engine runs at almost exactly the same speed, ever much the resistance may vary.

9. *The Fly-Wheel.*—As the crank turns round, it be seen that there are two points where the pis- od is pushing exactly in the direction of the point d which the crank moves; and that at these points es not tend to turn the crank at all. There must fore be some means of carrying the crank past these *points*, as they are called. This is the office of the *heel V*, a heavy iron wheel attached to the axle *D*. great *momentum* (99) of this heavy mass tends to the axle round with a uniform motion, notwith- ing the variations in the power acting upon it.

). *High Pressure and Low Pressure Engines.*— n the steam, after doing its work in the cylinder, is *ed into a cold chamber*, the engine is said to be of *pressure;* when it is *forced out into the air*, the e is said to be of *high pressure.* In the former *the steam is condensed into water in the cold ber, and a vacuum is thus formed behind the n.* In the latter case, *the piston has to act against*

the pressure of the atmosphere, which, as we have learned (74), is equivalent to a weight of 15 pounds on each square inch of its surface. It is evident that a greater pressure of steam will be necessary to move the piston in the latter case.

141. *The Boiler.*—In the boiler, *the steam is produced, and confined until it is used* in moving the piston.

Boilers are usually made of plates of wrought iron or copper riveted together. Copper is the best material, but iron is generally used on account of its cheapness.

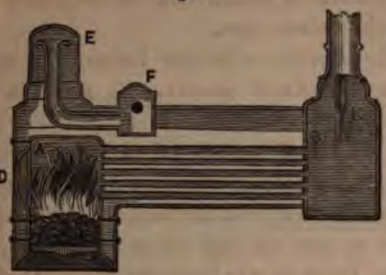
In order to get the full effect of the fire, *the hot gas and smoke from it are usually made to pass through flues or tubes in the body of the boiler;* and the water comes directly in contact with these flues or tubes. This is illustrated in the *Cornish boiler*, as it is called, shown in Figure 87, and considered one of the best forms of boiler. It is a cylinder, frequently more than forty feet long, and from five to seven feet in diameter, with two cylindrical flues, *B B*, extending its whole length. These flues serve as the furnace in which the fire is built. The hot gas and smoke, after passing through the flues, circulate round the outside of the boiler before escaping into the chimney.

Fig. 87.

Figure 88 represents the usual form of the boiler of a locomotive engine. The furnace, or *fire-box*, *A*, is within the boiler, and is surrounded by water except beneath and at the door *D*. A large number of stout tubes extend from the fire-box through the boiler to the *smoke-box B*. The hot gases and smoke pass through these before they escape into the chimney. *E* is the *steam-dome*, from the top of which a large tube conveys the steam into the

hamber *F*, from which it passes by tubes on each side o the cylinders. The waste steam from the cylinders

Fig. 88.

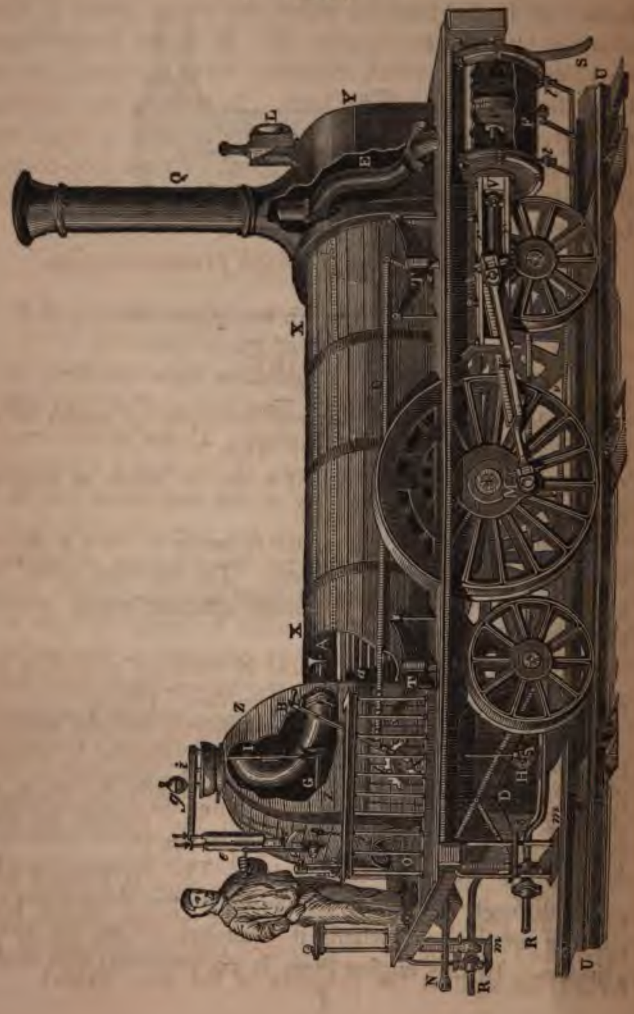


passes into the chimney through two pipes meeting at *K*, and thus increases the draught of the furnace.

142. *The Locomotive Engine.* — This machine is shown in full in Figure 89. The boiler *X X* has just been described. *D* is the fire-box; *Y*, the smoke-box; *a*, the tubes connecting the two; *O*, the door for putting in fuel; *H*, the *vent-cock*, by which the water can be drawn off from the boiler; *R R*, the *feeders* which conduct water from the *tender* to two force-pumps (not seen in the figure) by which it is forced into the boiler. At *i* are the *safety-valves*, kept down by spiral springs in the cases *e*. When the pressure of steam in the boiler becomes too great for safety, the valves open and, by allowing a part of the steam to escape, reduce the pressure. *g* is the *steam-whistle; G*, a rod which controls the valve *I*, by which steam is let into the steam-pipe *A*. The engineer is represented as holding in his hand the lever by which this valve is opened more or less, to regulate the speed of the engine. The *steam-tube A* passes through the boiler, as shown by the dotted lines, into the smoke-box, where it branches off to the two cylinders. In this engine there is no chamber, like that

marked *F*, in Figure 88. One of the cylinders is seen at *F*, laid open to show the piston *P*. The sliding valve

Fig. 89.



by which the steam is admitted to the cylinder is precisely like the one figured and described above (137); but, being behind F under the boiler, it does not appear here. E is the pipe by which the waste steam is discharged into the smoke-pipe Q. K is the *connecting-rod*, by means of which the piston turns the crank M on the axle of the *driving-wheels*. In starting the engine, the valves must be moved by hand. This is done by means of the lever B and the rod C. $t\ t$ are stop-cocks, through which any water condensed in the cylinders can be driven out; v, the rod for opening these cocks.

The locomotive is always a *high pressure* engine.

SUMMARY.

The *downward* and *lateral pressure of water* is a source of mechanical power. (133.)

The downward pressure of water is made to turn a *vertical* water wheel. (134.)

The lateral pressure of water is made to turn a *horizontal* or *reaction* water wheel. The *turbine wheel* is a reaction wheel, and the most efficient water wheel known. (135, 136.)

The *elastic force of steam* is used as a source of mechanical power in the *steam engine*. (137.)

The essential parts of the steam engine are the *boiler*, in which the steam is generated; the *cylinder*, in which the expansive force of the steam is made to work a piston; and the *crank*, by which the motion of the piston is made to turn a shaft, (141, 137.)

In the *low pressure* engine, a vacuum is formed behind the piston by condensing the steam which has been used; in the *high pressure* engine, this steam is forced out against the pressure of the air. (140.)

SOUND.

NATURE AND PROPAGATION OF SOUND.

143. *A Sounding Body is a Vibrating Body.*—If a glass bell-jar held by the knob be struck with the knuckle, it gives out a sound. If a bit of metal, ivory, or other hard substance be placed within the bell, as seen in Figure 90, it is tossed up and down rapidly, showing that the bell is *vibrating*.

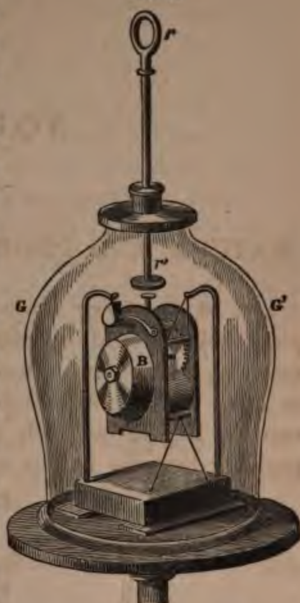
Fig. 90.

Every body vibrates while giving out sound, and it is only by causing a body to vibrate that it can be made to give out sound.

144. *Sound will not pass through a Vacuum.*—In Figure 91, the bell B is suspended by silk threads under the receiver of the air-pump. The bell is struck by means of clock-work, set in motion by the sliding rod r. If the bell be struck before exhausting the air, it can be distinctly heard; but as the air is exhausted, the sound becomes fainter and fainter, until at last it can hardly be perceived even with the ear close to the receiver. *Sound, then, cannot pass through a vacuum.*

The slight sound which is heard is transmitted by the little air left in the receiver, and by the cords which hold up the bell.

Fig. 91.



145. *Sound passes through all Gases.* — If hydrogen or any other gas be now allowed to pass into the receiver, the sound of the bell will be heard again.

146. *Sound passes through Liquids and Solids.* — If a bell be put under water and struck, it can be heard. If a person puts his ear close to the rail of an iron fence, and the rail be struck at a considerable distance, he hears the blow twice. The first sound comes through the rail; the second, which soon follows, comes through the air. These experiments show that *sound passes through liquids and solids.*

A slight scratch upon the iron rail, which could not be heard at all through the air, is heard distinctly when the ear is placed against the rail; showing that the solid transmits the sound better than the air. If the ear be placed near the ground, the tramp of horses or the tread of men can be heard at a great distance, the sound being conveyed by the solid earth.

A vibrating body throws the molecules of air, or other elastic medium around it, into vibration, and these vibrations are sent on from molecule to molecule until they reach the ear.

147. *The Intensity of Sound depends upon the Amplitude of the Vibrations.* — If the bell-jar in Figure 90 be struck lightly, it will give out a faint sound, and the bit of metal will be but slightly agitated; if it be struck a harder blow, it will give out a louder sound, and the metal will be more violently agitated. It is evident that in the latter case the bell-jar *moves backward and forward through a greater space* than in the former; in other words, that the *amplitude* of its vibrations is greater. The *intensity*, or *loudness*, of sound, then, *depends upon the amplitude of the vibrations* of the sounding body.

148. *The Intensity of Sound diminishes as the Square of the Distance of the Sounding Body increases.* — If we place a bell ten yards off, and four bells of the same size twenty yards off, we shall find that the sound of the one bell will be just equal to that of the four bells. At the distance of thirty yards, nine bells would be necessary to produce a sound equal to that of the one bell at ten yards. Sound, then, *diminishes in intensity as the square of the distance from the sounding body increases.*

149. *Speaking-Tubes.* — If the sound is prevented from spreading in all directions, it loses little of its intensity. Thus Biot found that, through one of the water-pipes of Paris, words spoken in a very low tone could be heard three-quarters of a mile off. The sides of the pipe kept the sound from spreading. Conversation can be carried on between distant parts of a large building by means of small tubes, called *speaking-tubes.*

150. *Sound travels through the Air at the Rate of 1,090 Feet a Second.* — The velocity of sound in air has been several times determined by experiment. In 1822, the French Board of Longitude chose two heights near

Paris, and from the top of each fired a cannon at intervals of ten minutes during the night. The time between seeing the flash and hearing the report was carefully noted at both stations, and the average of the results showed that sound travels through the air at the rate of 1,090 feet a second. In such experiments, the time taken by the light to pass between the stations is too small to be perceived.

151. *The Velocity of Sound in Water is about* 4,700 *Feet a Second.* — This was determined at the Lake of Geneva, in 1826, by Colladon and Sturm. They found that, when a bell was struck under water on one side of the lake, the sound could be distinctly heard at a distance of nine miles on the other side by putting the ear to one end of a tube whose other end was in the water. It was thus found that *the velocity of sound in water is about* 4,700 *feet a second.*

152. *Sound travels through Solids faster than through Air.* — It is found by the experiment with the iron rail mentioned above (146) that *the velocity of sound in a solid body is greater than in the air.*

153. *Sound is reflected on meeting a new Medium.* — Experiments show that when sound meets a new medium, it is reflected; and that, as in reflected motion (102), *the angle of reflection is equal to the angle of incidence.*

154. *Echoes.* — When there is a sufficient interval between the direct and the reflected sound, we hear the latter as an *echo.* The reflected sound has the same velocity as the direct sound, so that the echo of a pistol-shot from the face of a cliff 1,090 feet distant is heard two seconds after the explosion.

An echo in Woodstock Park repeats seventeen syllables by day, and twenty by night; one on the banks of the Lago del Lupo, above the fall of Terni, repeats fifteen.

In the whispering gallery of St. Paul's, the faintest sound is conveyed from one side of the dome to the other, but is not heard at any point between. At Carisbrook Castle, in the Isle of Wight, is a well, 210 feet deep and 12 wide, lined with smooth masonry. When a pin is dropped into the well, it is distinctly heard to strike the water.

In some cases, the sound is reflected several times, and a succession of echoes is heard, each feebler than the preceding, since a part of the sound is lost at each reflection.

Sounds are also *reflected from the clouds.* When the sky is clear, the report of a cannon on an open plain is short and sharp; while a cloud is sufficient to produce an echo like the rolling of distant thunder. A feeble echo also occurs *when sound passes from one mass of air to another of different density.*

SUMMARY.

Sound originates in a vibrating body. (143.)

It is not propagated through a vacuum. (144.)

It is propagated through all elastic substances, whether gases, liquids, or solids, by vibrations of their molecules. (145, 146.)

Its intensity increases with the amplitude of the vibrations, and diminishes as the square of the distance from the sounding body increases. (147, 148.)

The velocity of sound in air is 1,090 feet a second. (150.)

The velocity of sound in water is about 4,700 feet a second. Its velocity in solids is greater than in the air. (151, 152.)

On meeting a different medium, sound is reflected. (153.)

Echoes are due to reflected sound. (154.)

MUSICAL SOUNDS.

155. *Difference between Noise and Musical Sounds.* — In Figure 92, we have an instrument called the *gyroscope*, consisting mainly of a heavy brass ring *d* surrounding a disk which rests upon a steel axis. To this axis is fastened a small toothed wheel *W*. If a card *c* be held against the edge of the wheel when it is spinning rapidly, a very shrill musical sound is produced; as the speed is checked somewhat, the sound becomes less shrill. The more the speed is diminished, the less shrill the sound becomes, until finally we hear the separate taps of the teeth against the card.

Fig. 92.

We see, then, that *when the taps are sufficiently frequent, they blend so as to produce one continuous sound*, or a *musical sound*, as it is called.

In this experiment, the card is made to vibrate by striking the teeth of the wheel; and, as the teeth are at equal distances, the vibrations follow one another at equal intervals. A musical sound, then, is one in which *the vibrations recur at regular intervals.* If they do not recur at regular intervals, the sound is called a *noise.*

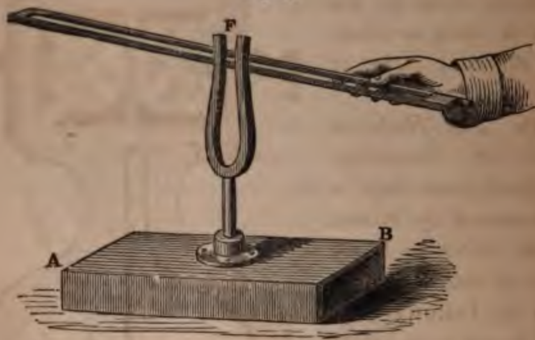
156. *The Pitch of Musical Sounds.* — We have seen that, the faster the wheel turns, and the more rapid the vibrations of the card, the shriller is the sound, or the

higher its *pitch*. Hence *the pitch of musical sounds depends on the rapidity of the vibrations.*

In musical sounds, as in all other sounds, the *loudness* depends upon the *amplitude* of the vibrations.

157. *The Tuning-Fork.*—The tuning-fork (Figure 93) consists of a bar of steel bent into the form of the

Fig. 93.



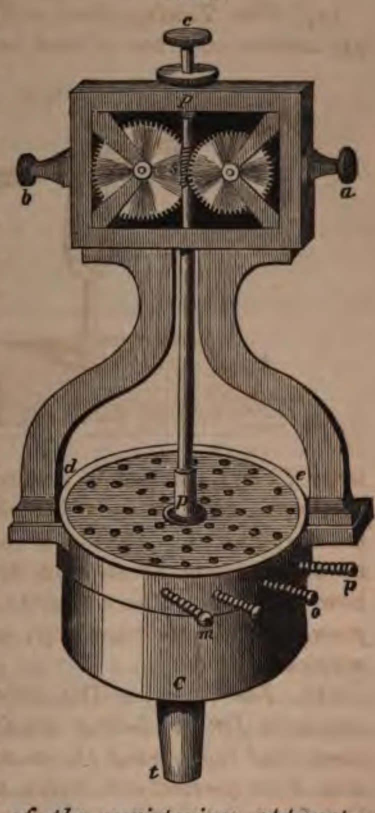
letter *U*, and attached to a standard. *A B* is a wooden case open at both ends, by which the intensity of the sound produced by the fork is increased. The fork may be set vibrating by striking it, or by drawing a violin bow across it. *The elasticity of the steel causes the prongs to vibrate regularly, and thus to give out a musical sound.*

158. *The Siren.*—The *siren* (Figure 94) is an *instrument for producing musical sounds, and at the same time registering the number of vibrations.* The disk *d e* is pierced with holes, and is made to rotate by blowing into the tube *t*. As it rotates, the holes are alternately opened and closed, so that the air escapes from the cylinder in a regular succession of puffs, giving rise to vibrations, which produce a musical sound.

The number of times the disk rotates is registered

by the apparatus shown in the upper part of the figure. On the axis of the disk is an endless screw *s* (132), which carries a pair of toothed wheels. These are connected with pointers moving over dial-plates on the front of the instrument. The stops *m*, *n*, *o*, *p*, are used to open or close the different sets of holes.

Fig. 94.



159. *The Rate at which a Sounding Body vibrates may be determined by means of the Siren.*—If we force air into the siren with a bellows, the disk is made to rotate faster and faster, and the pitch of the sound produced rises higher and higher, as the force of the blast increases. In this way, *the siren may be made to produce a sound of the same pitch as that of a tuning-fork*, or of any other sounding body; *and*, *by means of the registering apparatus, the number of vibrations in a second may be ascertained.*

160. *The Octave.*—A sound is the *octave* of another when it is *produced by vibrations twice as rapid.*

161. *The Sonometer.*—The *sonometer* (*sound measurer*), shown in Figure 95, consists of the sounding-board $M\ N$, above which the string $B\ B'$ is stretched upon

Fig. 95.

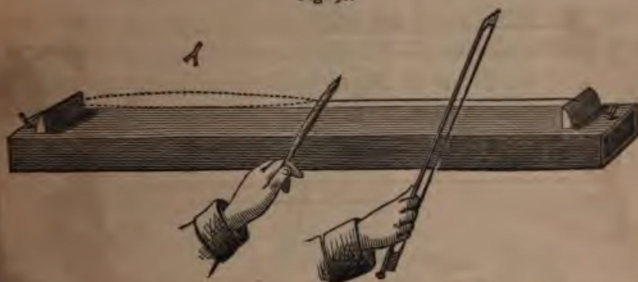
two movable bridges by means of the weight W. *It is used to illustrate the laws of the vibrations of strings.*

162. *The Rapidity with which a String vibrates is inversely as its Length.*—Cause the string $B\ B'$ to vibrate by pulling it to one side, or drawing a bow across it, and notice the pitch of the sound. Place one of the movable bridges at the centre of the string, so as to divide it into two equal parts, and cause either part to vibrate. The sound will be the octave (160) of the one given out by the whole string. The half of a string, then, vibrates twice as fast as the whole string, when the *tension* (or the tightness with which it is stretched) remains the same. In the same way, it can be proved that one-third of a string vibrates thrice as fast as the whole; and so on. While the string is equally stretched, *the rapidity of its vibrations is inversely as its length.*

163. *The Formation of Nodes.*—If we hold a feather against the centre of the wire of the sonometer (Figure

96), and draw a bow across one-half of it, we get the octave of the note given by the whole string, showing that one-half vibrates by itself. If now a little *rider* of

Fig. 96.



red paper be placed across the middle of one part of the string, and the other part be made to vibrate while the feather is still held at the centre, the rider is thrown off; showing that *both halves of the string vibrate*. These vibrating halves are separated by a *node*, or *stationary point*, formed where the feather touches the string.

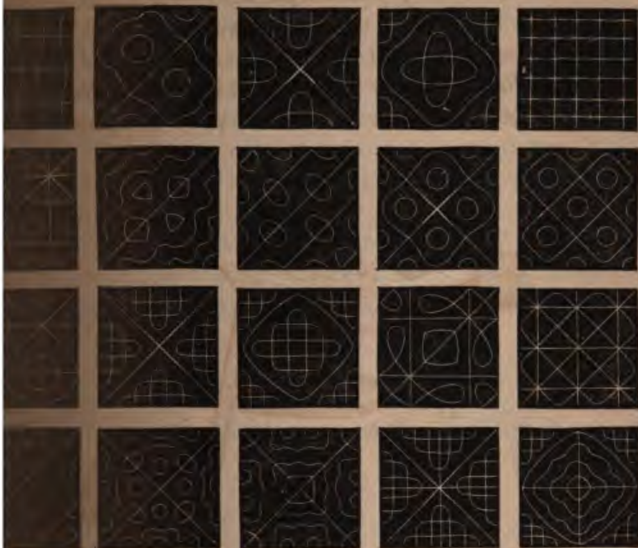
Hold now the feather one-third of the way from the end of the wire (Figure 97), and place a blue rider on

Fig. 97.

the longer portion of the wire, so as to divide it into two halves, and red ones on the middle of these halves. Now draw the bow across the shorter portion of the

sand, as in the above experiment. Some of these
al forms are shown in Figure 99.

Fig. 99.



Nodes may be formed in a similar way in bells, and all other sounding bodies.

165. *Overtones or Harmonics.*—It is found that, even hen a sounding body is made to vibrate as a whole, it ways does at the same time vibrate in parts; so that *vibrating body never gives out a simple tone.* The ne given out by a string, or other body, *as a whole*, is lled its *fundamental note;* the higher tones produced the vibrations *of the parts* are called *harmonics*, *overtones.* The *tone produced by the halves of a ring* is called the *first* harmonic; that *produced by thirds* of a string, the *second* harmonic; and on.

166. *Quality.* — In every vibrating string, a great number of these higher tones are produced, which, mingling with the fundamental tone, give rise to what is called the *quality* of the sound. It is this union of high and low tones which enables us to distinguish one musical instrument from another. A flute and a violin, though tuned to the same fundamental note, do not give the same sound. The overtones of the one are different from those of the other; and the mixtures formed by these and the fundamental note are therefore different.

167. — *Musical Sounds are transmitted through Liquids and Solids.* — In Figure 100, *M* is a long tube filled with water, which is placed between the tuning-fork *F* and the sounding-box *A B*. If the fork be set vibrating in the air away from the tube, it can scarcely be heard; but if the foot of it be placed upon the water in the tube, it can be heard as distinctly as when it is placed upon the sounding-box. In both cases, the box is the real sounding body, and is set vibrating by means of the tuning-fork. Musical vibrations, then, are transmitted through the water in the tube. Similar experiments prove that they are transmitted through all liquids.

Fig. 100.

By using a rod of wood in place of the tube, it may

ɜhown that ***musical sound is transmitted through ls*** as well as through liquids and gases.*

ꞩ8. *Sympathetic Vibrations.*—Place two tunings which sound the same note, mounted on their :s, upon the table, 18 inches apart, and draw the bow rously across one of them. If now we stop the ated fork, the sound is weakened, but by no means ıched. *The vibrations conveyed through the air through the wood have been taken up by the unhed fork*, and it is this fork which we now hear. .ch a bit of wax to one of the forks, and sound it n; the very slight change in the rate of vibration has royed the sympathy between the two forks, and no onse is now possible. Remove the wax, and the unhed fork responds as before.†

An experiment first tried by Wheatstone and repeated by lall is very striking. A piano was placed in a room underı the lecture-room, separated from the latter by two floors. ugh the two floors passed a tin tube 2½ inches in diameter, a wooden rod inside of it, the end of which projected into ecture-room. The rod was clasped by India-rubber bands h completely closed the tube. The lower end of the rod d upon the sounding-board of the piano. The piano was :d, and no sound was heard in the lecture-room; but when lin was placed against the end of the rod, it became musiıot with the vibrations of its own strings, but with those of ɔiano. On taking away the violin, the music ceased; but ı a guitar was put in its place, the sounds were heard ı; and also when a sounding-box was substituted for ɾuitar. The end of the rod was then placed against the ding-board of a harp, and every note of the piano was ɔduced as before.

ı ordinary music-box may be used instead of the piano in experiment.

Гhe vibrations may be communicated through the air alone. y one knows that a piano-string is sometimes set vibrating ı the note of the string is sounded by the voice or a flute, at the other end of the room.

8

When a body is thus thrown into vibration by its neighbor, its vibrations are said to be *sympathetic.*

169. *Two Sounds may Interfere so as to destroy each other and produce Silence.*—There are certain positions in which the sound of one prong of a tuning-fork is *wholly destroyed* by that of the other. These positions are easily found by making the fork vibrate, and then turning it round before the ear. When the back or the side of a prong is parallel to the ear, the sound is heard; when the corner of a prong is held toward the ear, the sound is utterly destroyed.

This case of *interference*, as it is called, may be rendered more striking by means of a *resonant jar* (180). In Figure 101, the jar is of such a length as to resound

Fig. 101.

powerfully to the fork. Rotate the fork above the mouth of the jar. When the back or sides of the prongs face the jar, a loud sound is obtained; but when the corners of the fork face the jar, there is no sound.

When the corner of the fork is over the jar, slide a pasteboard tube over one prong so as to cut off its vibrations, and the jar begins to resound.

170. *Beats.* — If two tuning-forks which vibrate nearly the same rate be made to sound together, the sound, instead of being continuous, *rises and falls in quick succession*, producing what are called *beats.*

Beats are thus produced *whenever two musical sounds of nearly the same pitch are uttered together*, and the *number of beats per second is always equal to the difference between the two rates of vibration.*

171. *Combination of Musical Sounds.* — Take two tuning-forks, each of which gives 256 vibrations in a second, and set them vibrating. The two musical sounds flow together in a perfectly blended stream, and produce what is called *unison.* In this case, *the ratio of the vibrations is* 1 : 1.

Take now two forks, one of which makes 256 vibrations a second, and the other 512. For every vibration sent to the ear by the one fork, two vibrations are sent by the other, and the two notes blend harmoniously.

This combination, as we have seen, is called an *octave* (160); and the ratio of the vibrations is 1 : 2.

Take another pair of forks, which give 256 and 384 vibrations in a second. The combination of the two sounds is very pleasing to the ear, but the consonance is hardly so perfect as in the case of the octave. The ratio of the vibrations is 2 : 3. This is the most pleasing combination next to the octave, and is called a *fifth.*

If we take two forks whose vibrations are in the ratio 3 : 4, the interval is called a *fourth.* This combination is still agreeable, but not quite so agreeable as the fifth.

Thus, then, *with perfect unison* the *ratio of the vibrations* is 1 : 1; with *a note and its octave* it is 1 : 2; with *a note and its fifth* it is 2 : 3; and with *a note and its fourth* it is 3 : 4. *The combination of two notes is the more pleasing to the ear, the smaller the two numbers which express the ratio of their vibrations.*

Take now two forks whose rates of vibration are i ratio 4 : 5, or a *major third* apart; the harmony i perfect than in any of the cases which we have exam With the ratio 5 : 6, or that of a *minor third*, it is u less perfect still; and we now approach a limit b which a musical ear will not tolerate the combinat two sounds. If, for example, we sound together tw whose vibrations are in the ratio of 13 : 14, their nation is altogether discordant.

An *agreeable combination of two notes* is c *chord;* a *disagreeable* one, a *discord.*

SUMMARY.

When the vibrations of a sounding body take regular intervals and often enough, they give r *musical sound.* In a *noise*, the vibrations follow other at irregular intervals. (155.)

The *pitch* of the sound increases with the ra the vibrations. By means of the *siren*, we m tain the number of vibrations answering to a pitch. (156, 159.)

Strings, plates, and all sounding bodies may v p—s separated by nodes. (163, 164.)

Sounding bodies always vibrate in parts, givi *overtones* or *harmonics;* and the blending of th tions gives to the sound its *quality.* (165, 166.)

Musical sounds are transmitted through solid and gases. (167.)

A vibrating body may throw another body int thetic vibration. (168.)

Two musical sounds may *interfere* so as to silence. (169.)

When two musical sounds of nearly the same pitch are sounded together, *beats* are produced. (170.)

When the combination of two notes is agreeable, they form a *chord;* when it is disagreeable, a *discord.* The simpler the ratio of the vibrations of two notes, the more agreeable the chord which they form. (171.)

MUSICAL INSTRUMENTS.

STRINGED INSTRUMENTS.

172. *Stringed Instruments.* — In *stringed* instruments the *sounds are produced by the vibrations of strings or wires.*

173. *Sounding-Boards.* — Some kind of a sounding-board is necessary in all stringed instruments.

It is not the chords of a piano, or harp, or violin, that throw the air into sonorous vibrations. It is the large surfaces connected with the strings, and the air enclosed by these surfaces. The merit of such instruments *depends mainly upon the quality and arrangement of their sounding-boards.*

174. *Laws of the Vibration of Strings.* — The first law of the vibration of strings has already been found (162), and is stated thus: *The rapidity of the vibrations is inversely as the length of the string.*

175. *The Rapidity with which a String vibrates varies as the Square Root of the Weight which stretches it.* — If a string be stretched on the sonometer (161) with a weight of one pound and made to vibrate, a note of a certain pitch is obtained. If the weight be made four pounds, the pitch will be raised

an octave; if sixteen pounds, it will be raised another octave; and so on. *The rapidity of the vibrations*, then, *varies as the square root of the weight by which the string is stretched.*

176. *The Rapidity with which a String vibrates varies inversely as its Thickness.*—If strings of the same material, but of different thickness, be stretched by equal weights, the thicker strings will give the lower notes. If one string is just twice as thick as another, its note will be an octave lower. Other things being equal, *the rapidity of the vibrations of a string varies inversely as its thickness.*

177. *The Rapidity with which a String vibrates is inversely as the Square Root of its Density.*—If a platinum and an iron wire of the same length and thickness be stretched by equal weights, they will not give notes of the same pitch. It is found that *the pitch of the sound rises as the square root of the density diminishes.*

The last two laws, taken together, may be stated thus: *The rapidity with which strings vibrate is inversely proportional to the square root of their weight.*

In one class of stringed instruments, like the violin, violoncello, and guitar, *notes of a great variety of pitch are obtained from a few strings by fingering the strings, so as to change their length.* In another class, like the harp and piano-forte, *many strings are used, varying in length and thickness, each of which gives but one note.*

SUMMARY.

Musical sounds may be produced by the vibrations of strings, but a sounding-board is necessary to make them audible. (172, 173.)

vs of vibrating strings are three in number: —
e rapidity with which a string vibrates varies
as its length.
e rapidity with which a string vibrates varies
uare root of the weight which stretches it.
e rapidity with which a string vibrates is in-
the square root of its weight.
stringed instruments many notes are produced
strings; in others, there are as many strings as
notes given. (174–177.)

WIND INSTRUMENTS.

he Longitudinal Vibrations of Rods free at
. — A smooth wooden or metallic rod, with
s ends fixed in a vice, yields a musical note
bed with resined leather. The rod lengthens
ens in quick succession, or, in other words, is
nto *longitudinal vibration.* The pitch of the
eases as the length of the rod diminishes.
o2 shows a musical instrument whose notes
uced by the longitudinal
of wooden rods of dif-
gths.

Fig. 102.

ongitudinal Vibrations of
e at both Ends. — Clasp
ass tube at its centre with
, and rub a wet cloth over
s halves with the other.
l sound is produced. A
s rod of the same length
the same note. In this
centre of the tube, or rod,
(163), and the two halves

lengthen and shorten in quick succession. In
103, *a b* is a brass rod held at its centre by the

Fig. 103.

s; and an ivory ball hung by two strings fro
points *m* and *n* rests against the end *b* of the roc
drawing a piece of resined leather gently over t

Fig. 104.

near *a*, we throw it into longi
vibrations. The centre *s* is at r
the motion of the ivory ball show
the end *b* is in a state of tremor.
the rod more briskly, and its vib
become more intense, and the
ball is thrown off violently wh
it comes in contact with the
the rod.

If a long glass tube be held
centre, and one-half of it be
briskly with a wet cloth, the
upon the glass, caused by the
tudinal vibrations, may be suffic
shiver the other end, as shown i
ure 104.

180. *Resonance.* — When a t
fork is detached from the sounding-box, and m
vibrate, it can hardly be heard. Let, now, the f

over a glass jar *A B* (Figure 105), some 18 inches
, and the sound is still very faint. Keep the fork
his position, and
r water with the
t possible noise into
jar. As the col-
n of air under the
k becomes shorter,
sound becomes
der; and when the
ter has reached a
tain level, it bursts
h with great power.
ntinue to pour water
the jar, and the
nd becomes weaker
weaker, until it is
faint as at first.
r the water care-
y out, and we reach
int where the sound
einforced again. In this way, we find that *there
ne particular length of the column of air which
ses the fork above it to give the loudest possible
nd.* This *reinforcement of sound* is called *reso-
ce.**

Fig. 105.

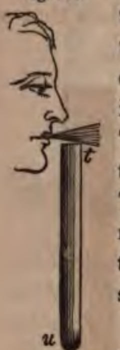
he columns become shorter as the forks vibrate
er.

* "Most travellers in Switzerland have noticed the deafening
nd produced by the fall of the Reuss at the Devil's Bridge.
noise of the fall is raised by resonance to the intensity
hunder. The sound heard when a hollow shell is placed
e to the ear is a case of resonance. Children think they
r in it the sound of the sea. The noise is really due to
reinforcement of the feeble sounds with which even the
est air is pervaded. The channel of the ear itself is also

181. *A Column of Air may be made to vibrate by blowing across the End of a Tube.* — Select two jars, and two tuning-forks to which they will resound. Make both forks vibrate, and hold them both over one of the jars. Only one of them is heard. Hold them both over the other jar, and the other fork alone is heard. If twenty forks were held over either of these jars, it would select and reinforce the sound of the one to which it naturally resounds.

Blow, now, across the open mouth of this same jar or across the mouth of a glass tube of the same length as the jar, and $\frac{3}{4}$ of an inch in diameter (Figure 106). A fluttering of the air, a mere medley of vibrations, is thus produced at the mouth of the tube. The tube selects the set of vibrations or *pulse*, to which it can resound, and reinforces it so that it becomes a musical sound. The sound is the same as that produced by the proper tuning-fork held over the tube. The column of air in the tube has, in fact, made its own tuning-fork; for it has made the air blown across the tube vibrate in unison with itself.

Fig. 106.



On blowing across the mouth of a tube of any length, *a musical sound is produced exactly like that obtained when the proper tuning-fork is held over the tube.*

182. *The Rate of Vibration of a Column of Air in a Tube is inversely proportional to its Length.* — Take three tubes, 6, 3, and $1\frac{1}{2}$ inches long, and blow gently

a resonant cavity. When a poker is held by two strings, and when the fingers of the hands holding the poker are thrust into the ears, on striking the poker against a piece of wood a sound is heard as deep and sonorous as that of a cathedral bell." — *Tyndall.*

across the mouth of each, so as to bring out its fundamental note (165). The note of the 3-inch tube will be the octave of the note of the 6-inch tube, and that of the $1\frac{1}{2}$-inch tube the octave of that of the 3-inch tube. In other words, *the rate of vibration is inversely proportional to the length of the tube.*

183. *Vibrations in Open Tubes.*—The tubes which have been used thus far have been *closed at one end.* Such tubes are called *stopped* tubes. We will next examine the vibrations of tubes *open at both ends*, or *open* tubes. If we take a stopped tube and an open tube of the same length, and blow gently across the mouth of each so as to get its fundamental note, we find the note of the latter an octave higher than that of

Fig. 107.

Fig. 108.

the former. *An open tube always yields the*
of the note given by a stopped tube of the same l

184. *Organ-Pipes.* — Organ-pipes are nothing
than *resonant tubes.* There are various ways of
ing the air at the mouth of such tubes, so as
the columns of air within them into vibrations.
kind of organ-pipes, this is done by blowing
sheet of air against a sharp edge. This prod
flutter, some *pulse* (181) of which is *converted*
musical sound by the resonance of the air in th

Figures 107 and 108 represent *open* organ-pipes.
air passes from the bellows through the tube *P*
chamber, which is closed at the top except the
slit *i*. The air compressed in the chamber
through this slit in a thin sheet, which breaks
the sharp edge *a*, and there produces a flutter.
space between the edge *a* and the slit below is
the *mouth* of the pipe.

In a *stopped* organ-pipe, the upper end is

Fig. 109.

Instead of producing a
at the mouth of the
by a blast of air, w
get the same effect b
ing at the mouth of th
(Figure 109) a tuni
whose vibrations are
son with those of the
Select several pipes of
ent lengths, and tunin
in unison with each.
ning with the longest
make the fork of lowes
vibrate near its mouth.
pipe *speaks* loudly. B
to the same pipe; its

exactly the same as when the fork was held at its mouth. Try each pipe in the same way, and the note which each gives when blown into is exactly that given when the proper fork is at its mouth. If all the forks are held at the same time at the mouth of any one of the pipes, the pipe will select and reinforce the sound of but one. So also the current of air striking against the sharp upper edge of the mouth of the pipe gives rise to a great variety of pulses, from which the pipe selects and reinforces but one.

185. *Reed Pipes.* — A column of air may be made to vibrate by means of *a spring of metal, or wood,* called a *reed.* The metal reed commonly used in organ-pipes is shown in Figure 110. It consists of a long and flexi-

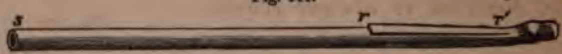
Fig. 110.

ble strip of metal, *V V*, placed in an opening through which the air enters the pipe. As soon as the air begins to enter the pipe, the force of the blast bends down the spring of the reed so as to close the opening. The elasticity of the reed causes it to fly back at once, so as to open the pipe and allow the air to enter again. It thus breaks up the current of air into a regular succession of little puffs.

The action of the reed may be illustrated by a common straw. With a penknife raise a strip of the straw near a knot, as shown at *r r'* in Figure 111. This strip

serves as a reed, and the straw as a pipe. Blow into it, and it gives a musical note.

Fig. 111.



In the horn, trumpet, and similar instruments, the lips of the player take the place of the reed.

186. *Two Classes of Wind Instruments.*—In one class of wind instruments, as the flute and fife, *a single column of air is made to give a great number of notes,* the length of the column being varied by keys. In another class, as the organ, *there is a pipe for every note.*

SUMMARY.

Longitudinal vibrations may be illustrated by means of rods free at one end or at both ends. (178, 179.)

The sound of a tuning-fork is reinforced when it vibrates over the mouth of a jar of air of a certain depth. This reinforcement of sound is called *resonance.* (180.)

Jars and tubes may be made resonant by blowing across their open mouths, and give the same note as when made to resound by a tuning-fork. The shorter the column of air, the faster it vibrates. (181, 182.)

An open tube gives a note which is the octave of a closed tube of the same length. (183.)

Organ-pipes are resonant tubes. When open at both ends, they are called *open* pipes; when closed at one end, *stopped* pipes.

One kind of organ-pipe is made to resound by blowing a thin sheet of air against a sharp edge at its mouth. (184.)

A column of air may be made to vibrate by means of a *reed.* The trumpet and many other wind instruments are reed-pipes. (185.)

SOUNDING FLAMES.

Friction is always Rhyth- -When we draw a bow across ıg, or rub a wet finger round ge of a glass, a musical sound ıduced, showing that the fric- as been broken up into rhyth- ulses. Close the lower end of ıbe *A B* (Figure 112) with a lic plate, pierced by a round vhose diameter is equal to the ıess of the plate. Plug the and fill the tube with water. ıve the plug, and, as the water in the tube, a very sweet musi- ıte is given out by the liquid ın. This note is due to the in- tent flow of the water through ıle, by which the column above ıwn into vibrations. The same ıittence is observed in the dense : which rolls in rhythmic rings the funnel of a steamboat. A rifle-ball sings as ses through the air. "The whispering pines" owe music to the rubbing of the wind against their ıes and foliage. The whistling of the wind is ıroduced by the rhythmic friction of the air.

Fig. 112.

ıe blow gently against a candle-flame, the fluttering announces a rhythmic action. We have learned that a pipe will select a pulse from a flutter, and t by resonance to a musical sound. In like manner, *oise of a flame may be converted into a musical* This is done by enclosing the flame in a tube.

188. *Sensitive Flames within Tubes.*—Place a tube 12 inches long over a small gas-flame, so that the flame shall be about an inch and a half from the bottom of the tube. If the note to which the tube would resound be sounded at some distance, the flame is seen to tremble. Lower the tube, so that the flame shall be about three inches from the bottom, and the flame begins to sing. Somewhere between these two points we may find a point where the flame will burn silently; but *if it be excited by the voice, it will sing, and keep on singing.*

Flames which are thus *affected by musical sounds* are called *sensitive* flames.

SUMMARY.

Friction is always rhythmic.

When a gas-flame is surrounded by a tube, the air in passing over it is made to vibrate, and musical sounds are produced. A silent flame within a tube may be made to sing by sounding the note of the tube near it. (187, 188.)

THE HUMAN VOICE AND EAR.

189. *The Organ of Voice is a Reed Instrument.*—The organ of voice in man is situated at the top of the windpipe, or *trachea*, which is *the tube through which the air is blown from the lungs.* A pair of elastic bands, called *the vocal chords*, stretched across the top of the windpipe, so as nearly to close it, form *a double reed.* When the air is forced from the lungs through the slit between these chords, they are made to vibrate. By changes in their tension, their rate of vibration is varied, and the sound raised or lowered in pitch. The *cavity of the mouth and nose* acts as a *resonant tube.*

he action of the vocal chords may be imitated by means of india-rubber bands. If the open end of a glass tube (Figure 113) be closed by two strips of india-rubber, leaving a slit between them, and the air be blown through this slit, the strips are thrown into vibration, and a musical sound is produced.

Fig. 113.

90. *The Human Ear.*—The external opening of

Fig. 114.

ear (Figure 114) is closed at the bottom by a mem-
ie, called the *tympanum*. Behind this is the cavity
ed the *drum* of the ear. This is separated from
space between it and the brain by a bony partition,
which there are two openings, the one round and
other oval. These also are closed by delicate me
ies. Across the cavity of the drum stretches a
our little bones: the first, called the *hamme*s path;
ed to the tympanum; the second, called ight lines.

is connected by a joint with the hammer; a third little round bone connects the anvil with the *stirrup bone*, which has its oval base planted against the membrane of the oval opening. Behind the bony partition is the *labyrinth*, which is filled with water, and over the lining of which the fibres of the *auditory nerve* are spread. The tympanum receives the vibrations of the air, and transmits them through the series of bones to the membrane which separates the drum from the labyrinth; and thence to the liquid within the labyrinth, which transmits them to the nerves. The nerve transmits the impression to the brain and thus to the mind.

191. *The Range of the Human Ear.* — There must be at least 16 vibrations in a second, in order that they may be heard as a continuous sound (155); and the sound ceases to be audible when the vibrations reach 38,000 in a second. Starting with 16 and multiplying continually by 2, we find that the 11th octave will have 32,768 vibrations. Thus *the entire range of the human ear extends to about* 11 *octaves*. The practical *range of musical sounds is about* 7 *octaves*, or from 40 to 4,000 vibrations in a second.

SUMMARY.

The organ of voice in man is a reed instrument, the *vocal chords* forming the reed. (189.)

The human ear consists of three parts: the outer ear, the drum, and the labyrinth. The sonorous vibrations are first intercepted by the tympanum, then trans- tted to the fluid in the labyrinth, by which they are unicated to the auditory nerve. (190.)

range of human hearing embraces about eleven (191.)

LIGHT.

PROPAGATION OF LIGHT.

RADIATION, REFLECTION, AND REFRACTION.

192. *A Luminous Body sends out Light in Every Direction.*—A body *in which light is developed* is called a *luminous* body. All other bodies are said to be *non-luminous*. If a lighted lamp is placed in the middle of a room, it illumines every part of the room; showing that the light proceeds from the luminous body in every direction.

A body *through which light passes*, as air and glass, is called *transparent*. Other bodies are called *opaque*.

193. *Light travels through Space in Straight Lines.*—If a room be darkened, and the sunlight be allowed to enter through a small hole in the shutter, it will illumine the floating particles of dust in the air

Fig. 115.

through which it passes, so that we can trace its path; and in every case we find that it moves in a straight lines.

An opaque body placed before a luminous one *cuts off the light from the space behind it*, producing a *shadow*.

If the luminous body *S* (Figure 115) is a mere point, the body *M* will cast a *well-defined* shadow *G H* upon the screen *P Q*.

If the luminous body *S L* (Figure 116) is not a mere point, the shadow cast by *M N* will have *an indistinct*

Fig. 116.

outline. The *dark central portion G H* of the shadow is called the *umbra;* the *less dark outer portion* is called the *penumbra. Umbra* is the Latin word for *shadow*, while *penumbra* means *almost a shadow.*

Since a luminous body *gives out light in every direction in straight lines*, it is said to *radiate* light. A *single line of light* is called a *ray*. A *collection of rays* is called a *pencil*. If *the rays are parallel*, it is a *parallel* pencil, or a *beam;* if *the rays diverge*, it is a *divergent* pencil; if *they converge*, a *convergent* pencil.

194. *The Velocity of Light is about* 190,000 *Miles a Second.*—Light moves so fast that it seems to require no time at all to pass over any distance on the earth. Its velocity was first determined by Roemer, a Danish astronomer, in 1675, by observing the eclipses of Jupiter's moons. Jupiter, like the earth, is a planet which revolves about the sun, but at a much greater distance than the earth. He is accompanied by four moons, which are cu eclipsed when they pass into his shadow; and the pre-

cise time when these eclipses occur can be calculated by astronomers. Roemer found that the eclipses did not always take place at the computed time, but appeared about sixteen minutes later when the earth was farthest from Jupiter than when she was nearest to him. He therefore concluded that it takes light sixteen minutes to traverse the difference of these distances, which is about 183,000,000 miles. Its velocity, then, would be about 190,000 miles a second, and this agrees very nearly with the velocity as determined by wholly different methods.

195. *The Intensity of Light diminishes as the Square of the Distance from the Luminous Body increases.*—In Figure 117, the disk $C\ D$ is held half-

Fig. 117.

way between the luminous point L and the screen $A\ B$. If the disk be held parallel to the screen, the diameter of the shadow on the screen will be twice that of the disk, and its surface will be four times that of the disk. The disk receives all the light that the space covered by the shadow would receive if the disk were removed. The light on the disk must then be four times as intense as that upon the screen. If the disk be held one-third of the way between L and the screen, the shadow will cover a surface nine times that of the disk, and the intensity of the light on the disk will be nine times as great as that upon the screen; and so on. The intensity of the light, then, diminishes as the square of the distance increases.

196. *Reflection and Refraction.* — If a ray of sunlight be made to fall upon a looking-glass in a darkened room, it will be seen to be *thrown back*, or *reflected*, from the glass.

A piece of glass cut into the form shown in Figure 118 is called a *prism*.

Fig. 118.

Fig. 119.

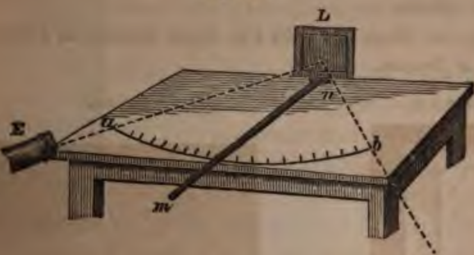
If a ray of light, *a b*, be allowed to fall obliquely upon one side of such a prism, as shown in Figure 119, a part of the light is reflected in the direction *b c*, and another part, *b d*, enters the prism. The part which enters the prism is bent from the direction of the original ray. When this part meets the air at the opposite side of the prism, a part of it is again reflected in the direction *d e*, and a part passes into the air, taking a different direction, *d f*, from that which it had while in the prism.

We see, then, that when light travelling in the air meets the glass, it is partly reflected and partly transmitted; and that when light travelling in the glass meets the air again, it is also partly reflected and partly transmitted. In both cases, *the transmitted portion is turned aside from its course.* Light thus *turned aside* is said to be *refracted.*

In general, *when light meets a transparent medium different from that which it has been traversing, it is partly reflected and partly transmitted. The transmitted portion, when it enters the medium obliquely, is refracted.*

197. *The Law of Reflection.* — In Figure 120, we have a mirror L fastened at right angles to the rod $m\ n$,

Fig. 120.



and turning upon a pivot at n. As the mirror is turned to the right or left, the rod passes over the graduated arc $a\ b$. If a ray of light be allowed to fall upon the mirror in the direction of the dotted line $a\ n$, it will be reflected in the direction of the line $n\ b$; and it will be seen that the angle $a\ n\ m$ is equal to the angle $b\ n\ m$. The former is called the *angle of incidence*, and the latter the *angle of reflection*. If the mirror be turned, the direction of the reflected ray changes in such a way that *the angle of incidence always equals the angle of reflection*. This is known as the *law of reflection*.

198. *Diffused Light.* — Since non-luminous bodies are not visible in the dark, but become visible when light falls upon them, they must send to our eyes some of the light they receive. This light must be sent out in every direction, since we can see them as well from one position as another. The light which they thus throw off is said to be *diffused*. It is this *diffused light* which *enables us to see the body itself;* while *reflected light enables us to see another body in it*. The most perfectly polished mirror does not reflect all the light it receives. It diffuses a portion, so that we see the mirror as well as the objects reflected in it.

199. *The Law of Refraction.*— When a ray of light passes obliquely from air into water, it is *bent towards a perpendicular drawn to the surface* of the water. Thus the ray *a b* (Figure 121) is bent towards the perpendicular *c d*, and takes the direction *b e* after passing into the water. This is found to be always true *when the light passes from a rarer to a denser medium. When it passes from a denser to a rarer medium, it is bent away from a perpendicular drawn to the surface* of the latter medium.

Fig. 121.

It is owing to refraction that a stick placed obliquely in the water appears bent, as in Figure 122. Each part of the stick in the water appears to be lifted up a little by refraction.

Fig. 122.

200. *Total Reflection.*—When a ray of light passes from a denser to a rarer medium, as from water into air, the angle of refraction is greater than the angle of incidence (199). Hence when light passes through water from *S* to *O* (Figure 123), there is always a value of the angle of incidence *S O B* such that the angle of refraction *A O R* is a right angle. In this case, the ray cannot pass from the water into the air. *If the incident angle be made any larger, the light is thrown back* in the direction of *Q*, and is said to be *totally reflected.*

Fig. 123.

201. *Mirage.*—In hot climates, especially on the Sahara in Africa, the ground has often the appearance of a tranquil lake, on which are seen

eflected houses and trees. This is *caused by total reflection*. The layers of air near the ground are more heated, and therefore less dense than those higher up. A ray of light, then, coming from A (Figure 124) is

Fig. 124.

bent round more and more as it passes down through the successive layers until it reaches the point O, where the angle of incidence becomes such that it is totally reflected, and reaches the eye as if it came from B. The same will be true of light coming from other parts of the tree, so that the tree will appear inverted, as if reflected in water. This phenomenon is called *mirage*, and often deludes the thirsty traveller on the desert with the appearance of water which vanishes as he draws near it.

Another form of mirage is often seen on the water. In this case, the layers of air near the water are colder and more dense than those above, so that the rays of light passing upward from an object are bent round more and more, until at last they are *totally reflected downward* to the eye of the observer, who thus sees the object inverted in the air.

202. *Path of Rays through a Medium with Parallel Faces.*—When light passes through a medium with parallel faces, as a pane of common window-glass, *the rays leave this medium at the same angle at which they entered it.* Since the ray in passing into the air is bent away from the perpendicular just as much as it was bent towards it in passing into the glass, the ray leaves the glass at the same angle at which it entered it; and its direction, therefore, is unchanged.

203. *Path of Rays through a Prism.*—In Figure 125, the ray of light *O D* on passing into the prism *A B C* is bent towards a perpendicular drawn to the surface at *D*. On passing out into the air again, it is bent away from a perpendicular drawn to the surface at *K*. We see, then, that *a ray of light in passing through a prism is bent twice in the same direction;* provided it meets neither face at right angles.

Fig. 125.

SUMMARY.

A luminous body gives out light in every direction, which passes through space in straight lines.

A single line of light is called a *ray;* and a collection of rays, a *beam*, or *pencil.* (192, 193.)

The velocity of light is about 190,000 miles a second. (194.)

The intensity of light diminishes as the square of the distance increases. (195.)

When light falls on a transparent medium different from that in which it is moving, it is partially reflected

partially transmitted. The transmitted portion, meets the medium obliquely, is refracted. (196,
)
ne angle of reflection equals the angle of incidence.
.)
ll bodies diffuse light, and it is by means of this ised light that we see them. (198.)
n meeting a rarer medium at a certain angle, light otally reflected. (200.)
lirage, and other atmospheric phenomena of the d, are caused by total reflection. (201.)
Vhen a ray passes through a medium with parallel es, it comes out with its direction unchanged. (202.)
)n passing through a prism, a ray is usually bent ce in the same direction. (203.)

ISPERSION, ABSORPTION, INTERFERENCE, AND POLARIZATION.

204. *The Solar Spectrum.* — Allow a beam of sunht, SA (Figure 126) to pass through a small opening

Fig. 126.

o a darkened room, and fall upon the prism P. If prism be placed at the proper angle, the beam of

light is not only bent from its course, but is spread out so as to form a long band of light on the opposite wall. This band is not white, like ordinary sunlight, but made up of the seven colors of the rainbow, *violet, indigo, blue, green, yellow, orange,* and *red.* This colored band is called the *solar spectrum,* and the colors are often called the *prismatic colors.*

This *spreading out of a beam of light* is called *dispersion;* and the power of any substance to produce this effect is called its *dispersive power. The dispersive power of a substance is not in proportion to its refractive power.* Thus the refractive power of flint-glass is almost the same as that of crown-glass, but its dispersive power is nearly double.

205. *Achromatic Prism.* — By combining a flint-glass prism *C D F* (Figure 127), with a crown-glass prism *C B F*, the dispersive power of the latter may be neutralized, without wholly neutralizing its refractive power. The prism *C D F*, in order to have the same dispersive power as *C B F*, need be only half as thick as the latter; so that the edges *B C* and *F D* are still inclined as though they were sides of the larger prism *A B F*.

Fig. 127.

Such a combination of prisms is called an *achromatic* (*colorless*) prism, since *light passes through it without being separated into the prismatic colors.*

206. *The Prismatic Colors are Simple.* — If all the colors of the spectrum except one be cut off by a screen, and that one be made to fall on a second prism (Figure 128), it will be again refracted, but *will not be separated into different colors.* These colors, then, are *simple.*

207. *The Prismatic Colors are unequally Refrangible.* — The position of the colors in the spectrum shows

t they are not equally refracted. *The red is least, d the violet most refracted.*

Fig. 128.

ɔo8. *The Composition of White Light.* — These ex- riments with the prism seem to show that *white light not simple, but made up of the seven prismatic ors.*

The same may be shown by *mixing these colors in the* . This can be done by painting them in the proper portions upon a circular disk (Figure 129) and mak-

Fig. 129.

Fig. 130.

this disk whirl rapidly, as shown in Figure 130. The pression of each color remains in the eye while the

disk turns completely round, so that the seven are *blended into one*, and the disk appears *white*.

If we mix two or more of these colors, we get a tint different from any one of them. Thus red and yellow produce orange; blue and red, purple; and so on. In fact, all the varied colors we see are formed by the mixture of the prismatic colors.

It is probable that white light is made up of *only three simple colors;* for if *red*, *green*, *and blue* be mixed, a color is obtained which cannot be distinguished from white. Moreover, all the other prismatic colors can be formed by mixing these three.

According to some authorities, *red*, *yellow*, *and blue* are the three simple colors; but it has been shown that no mixture of these will produce all the prismatic colors.

If the spectrum be *divided into any two parts*, *and the colors in each part be mixed*, they will form what are called *complementary* colors; that is, *one will contain what the other needs to make white light*.

209. *Absorption of Light.* — If light be made to pass through a piece of colored glass, and then to fall upon a prism, the spectrum will be wanting in certain colors. If red glass is used, the spectrum will contain little besides red light; if blue or green glass is used, the spectrum will be rich in blue or green, and deficient in other colors. *A part of the light is retained in the glass*, and is said to be *absorbed* by it. *All transparent bodies absorb a portion of the light which falls upon them.* If they absorb all colors equally, they appear colorless; if they absorb some colors more than others, their color will be *complementary* to what they thus absorb (208).

210. *The Color of Bodies.* — Opaque bodies, as well as transparent ones, absorb light. Hence, when white light is falling upon non-luminous bodies, they do not all appear of the same color. They are really *sifting* the

light which they receive, absorbing a part and reflecting, diffusing, or transmitting the rest. *Their color depends upon the light which they reflect or diffuse.* Thus a body which absorbs all the prismatic colors except red appears red; one which absorbs all except green appears green; and so on.

Bodies sometimes *transmit* a color different from that which they *reflect*, and *appear of a different color according as they are seen by transmitted or reflected light.* Gold appears yellow by reflected light, and green by transmitted light, as may be seen by holding a piece of gold-leaf between the eye and the sunshine.

211. *Two Rays of Light may Interfere so as to Destroy each other.* — If a slightly curved piece of glass be pressed down upon a flat plate of glass (Figure 131), colored rings are formed around the centre (Figure 132).

Fig. 131.

Fig. 132.

If any *homogeneous* light (that is, light *of one kind*), as red, be used, the rings are red and separated by black spaces. If violet light be used, the rings are violet and smaller. As we pass from the violet end of the spectrum to the red end, the rings grow larger and broader. Hence, when white light is used, we get seven sets of rings, which somewhat overlap one another. This explains why there are several colors in each ring. The dark rings are caused by the *interference* of the rays of light which are reflected from the lower surface of the upper glass and the upper surface of the lower glass. Hence two rays of light, like two sounds (169), may interfere so as to destroy each other. These colored rings are seen in soap-bubbles, and in all cases where there are two reflecting surfaces very near each other. They are known as *Newton's rings*, since he was the first to study them.

212. *Diffraction Fringes.*—Let a beam of sunlight fall upon a small glass lens* in a darkened room. The light will be concentrated into a point a little way from the lens, and will then diverge from it in a luminous cone, and may be received upon a screen. Place any small opaque body within this cone of light, so that it may cast a shadow upon the screen. This shadow, instead of being sharply defined, as we should expect (193), is somewhat larger than it should be, and is *surrounded by three colored fringes.* If homogeneous light (211) is used, instead of the fringes we get bright rings separated by dark spaces, the breadth of the rings varying with the color of the light. When white light is used, these different sets of colored rings blend so as to produce the fringes.

If the opaque body is long and very narrow, as a hair or a very thin strip of card, besides the colored fringes already described, others are seen within the shadow, parallel to its length, and arranged on the two sides of a central white line.

When light is transmitted through a very narrow slit, the fringes become even more curious and complicated.

These fringes are called *diffraction fringes*, and are *caused by interference.*

213. *Double Refraction of Light.*—Figure 133 represents a crystal of *Iceland spar* (crystallized carbonate of lime). A crystal of this shape is called a *rhomb.* It has six faces, which are equal parallelograms. If now a ray of light be allowed to fall on one face of this crystal in a darkened room, it will be

Fig. 133.

* The focal length of the lens should be about an inch.

doubly refracted, or divided into two rays. One of these rays *conforms to the law of ordinary refraction* (199), and is therefore called the *ordinary* ray. The other ray does not conform to this law. It is therefore called the *extraordinary* ray. Since the opposite faces of the crystal are parallel (202), the ordinary and extraordinary rays emerge parallel to the incident ray and to each other, but quite near together. If, however, the crystal be cut into the form of a prism, the ordinary and extraordinary rays, after leaving the prism, will diverge, so that we may easily examine them separately. Such a prism may be rendered sufficiently achromatic by combining with it a second prism of glass, whose dispersive power (204, 205) is different from that of the crystal. This prism is usually mounted as shown in Figure 134.

Fig. 134.

214. *The Ordinary and Extraordinary Rays are both Polarized.*—Let a beam of ordinary light fall on a double-refracting prism, cut off the extraordinary ray by a screen, and let the ordinary ray fall on a second similar prism. If this second prism be turned round, we find a position in which the ray is refracted *singly* and *ordinarily*, and another position in which it is refracted *singly* but *extraordinarily*. Half-way between these two positions, it will be *doubly* refracted.

If the ordinary ray be cut off, and the extraordinary ray be allowed to fall on the second prism, it will be singly or doubly refracted when the prism has been turned round 90° from the position in which the ordinary ray was singly or doubly refracted.

In this way, we find that neither of the doubly refracted rays is the same on the right and the left as it is above and below; in other words, both rays have acquired *sides*. In this respect, they differ from a ray of ordi-

nary light, which is doubly refracted in every position of the prism, and is therefore the same on all sides.

Light which has thus acquired sides is said to be *polarized. The corresponding sides of the two rays are at right angles to each other;* in other words, *the extraordinary ray is like the ordinary ray turned round through* 90°.

SUMMARY.

In passing through a prism, a beam of white light is *dispersed*, and forms a spectrum of seven colors. Since different substances disperse light differently, two prisms may be combined so as to form an *achromatic* prism. (204, 205.)

Prismatic colors are simple and unequally refrangible. (206, 207.)

The blending of the seven prismatic colors produces white light.

It is probable that there are but three simple colors, red, green, and blue.

Two colors, whose mixture will produce white light, are said to be *complementary*. (208.)

Different bodies *absorb* light of different colors. It is the sifting of the rays of light by absorption which gives bodies their color. (209, 210.)

Soap-bubbles and other thin films, when exposed to light, exhibit colored rings. These rings are always seen when light is reflected from two surfaces separated by a very small interval; and they are caused by *interference*. (211.)

When small bodies are seen in divergent light, they appear surrounded by colored fringes, called *diffraction* fringes. These are caused by interference. (212.)

When a ray of light passes through a crystal of Ice-

land spar, it is *doubly refracted;* one of the refracted rays being called the *ordinary*, and the other the *extraordinary* ray. (213.)

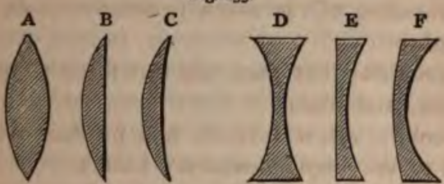
Both the doubly refracted rays have acquired *sides*, and are said to be *polarized*. Their corresponding sides are at right angles to each other. (214.)

OPTICAL INSTRUMENTS.

LENSES.

215. *Forms of Lenses.*—Lenses are *pieces of glass, or other transparent substance, bounded on one or both sides by a curved surface.* The forms of lenses used in optical instruments are shown in Figure 135.

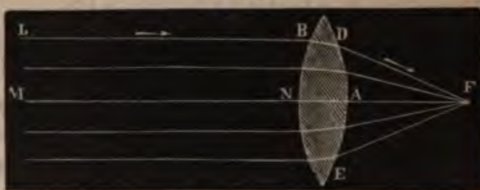
Fig. 135.



A is bounded by two spherical surfaces, and is called a *double-convex* lens. *B* has a spherical surface on one side, and a plane surface on the other, and is called a *plano-convex* lens. *C* has a convex surface on one side, and a slightly concave surface on the other, and is called a *meniscus*, from a Greek word meaning a *crescent*. *D* has two concave surfaces, and is called a *double-concave* lens. *E* has a concave and a plane surface, and is called a *plano-concave* lens. *F* has a concave surface on one side and a slightly convex surface on the other, and is called a *concavo-convex* lens.

216. *Convex Lenses cause Parallel Rays to Converge; Concave Lenses cause them to Diverge.*—Allow a beam of sunlight to fall upon a double-convex lens in a darkened room. On leaving the lens, *the rays will converge to a point*, called the *focus* (the Latin word for *fireplace*), since the heat as well as the light is concentrated there. This action of the lens upon the light will be understood from Figure 136. It will be seen

Fig. 136.



that the lens is somewhat like two prisms placed back to back; and it will be remembered that a ray of light, in passing through a prism (196), is bent twice in the same direction. The rays falling upon the upper part of the lens will be bent downward, and those falling on the lower part will be bent upward, and they will all meet at *F*. If a plano-convex lens, or a meniscus, be used, the results will be similar.

Parallel rays are made to meet at the focus of a convex lens. If, on the other hand, the rays *diverge from the focus*, they will become *parallel* on passing through the lens. If they *diverge from a point nearer the lens than the focus is*, they will be so divergent on entering the lens that they will not be made parallel on leaving it, but merely *less divergent*. If they *diverge from a point farther off than the focus*, they will be so little divergent that they will become *convergent* on leaving the lens.

If, however, we use any one of the *concave* lenses,

it will be found that the rays of light, instead of converging, are made to *diverge*, on leaving the lens; as shown in Figure 137.

Fig. 137.

Since the convex lenses all *cause parallel rays to converge*, they are called *converging* lenses; while the concave lenses are called *diverging* lenses, since they *cause parallel rays to diverge.*

217. *Images formed by Lenses.* — Place a lighted candle before a double-convex lens in a darkened room, and a screen behind it. At a certain distance from the lens, a distinct *inverted image* of the candle will be formed upon the screen. Move the candle nearer the lens, and the image will become blurred, but will become distinct again on moving the screen farther from the lens. If the candle be moved away from the lens, the image becomes blurred; but it becomes distinct again when the screen is brought nearer the lens. *The nearer the candle is to the lens, the larger the image formed.*

The more convex the lens used, *the nearer the candle must be brought* to it, and *the larger the image.*

Fig. 138.

Instead of using a more convex lens, we may add a second convex lens, with the same effect.

An image is formed behind a lens because the rays which diverge from every point of an object are made to converge, on passing through the lens, so as to meet at corresponding points behind the lens; as shown in Figure 138. The image is always included between lines drawn from the extremities of the object through the centre of the lens.

SUMMARY.

There are two classes of lenses. One class causes parallel rays to converge, and the other causes them to diverge. (215, 216.)

When objects are placed in front of a converging lens, images of them are formed at its focus behind it.

The magnitude of the image increases with its distance from the lens, and also with the convexity of the lens. (217.)

THE EYE.

218. *The Camera Obscura.*—If a converging lens be placed before an opening in the shutter of a darkened room, a small and beautiful picture of the landscape will be seen upon a screen placed a short distance behind the lens. An arrangement of this kind is called a *camera obscura* (Latin for *a dark chamber*).

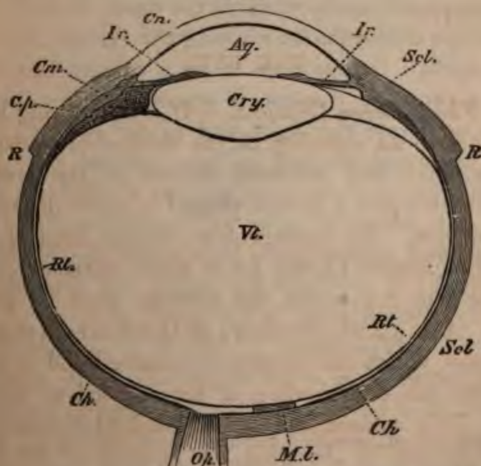
Figure 139 represents the camera used by photographers. C is a dark chamber; E is the screen of ground glass upon which the image is received; A is a tube containing the combination of lenses used to form the image. This camera can be adjusted to objects at different distances by changing the position of the screen, or of the lenses (which may be moved by the screw D), or both.

219. *The Eye is a Camera.* — The eyeball is composed, in the first place, of a tough, firm, spherical case,

Fig. 139.

Scl (Figure 140). The greater part of this case is white and opaque, and is called the *sclerotic* coat, or

Fig. 140.



the *white* of the eye. In front this case becomes trans-

parent and more convex, and is called the *cornea*, *Cn.* This case of the eye is kept in shape by being filled with fluids called the *humors*. The *aqueous* humor, *Aq*, fills the corneal chamber; and the *vitreous* humor, *Vt*, the sclerotic chamber. Between these chambers is the double-convex *crystalline lens*, *Cry*, which is denser, and has a greater refractive power than either humor. The *choroid coat*, *Ch*, is of a dark color and highly vascular (that is, *full of vessels*), and it lines the whole inner chamber of the eye. At the front part of the chamber, its inner surface becomes raised into ridges, called the *ciliary processes*, *C. p.*

The *iris*, *Ir*, is a curtain with a round hole in the middle called the *pupil*. The iris has two sets of muscular fibres, by the action of which the pupil is enlarged or contracted. It gives the *color* to the eye; and hence its name, *iris* being the Latin for *rainbow*.

The *optic nerve*, *Op*, enters the back of the eye a little way from the centre towards the nose. It then spreads out over the choroid coat, forming the *retina*, *Rt*.

The eyeball is thus seen to be a camera obscura.

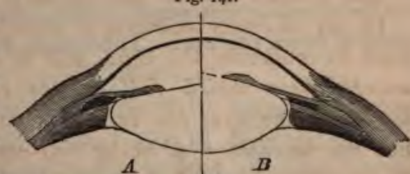
In an ordinary camera, a screen, or *diaphragm*, is used to moderate the light, and *to cut off all the rays except those which fall on the central part of the lens*. In the eye, *the iris acts as a diaphragm*, and has the advantage of being *self-regulating*. It dilates the pupil and admits more light when the illumination is too weak; it contracts the pupil, and cuts off a part of the light when there is too much of it.

220. *The Adjustment of the Eye.*—That the eye must adjust itself in order to see distinctly at different distances, may be shown by a very simple experiment. Stick two stout needles into a piece of wood, so that one of them shall be about six inches from the eye, and the other about twelve, very nearly in the same

direction. If now you look at one needle, you will see it distinctly and without the least sense of effort; but the image of the other will be blurred. Try now to make this blurred image distinct, and you find that you can do it, but not without effort. In proportion as one image becomes distinct, the other becomes blurred, and *no effort will enable you to see both distinctly at the same time.*

When a lighted taper is held near, and a little to one side of a person's eye, any one, on looking into the eye from the proper position, will see three images of the flame; one reflected from the cornea, one from the front surface of the crystalline lens, and one from its rear surface. Suppose, now, the person's eye be steadily fixed on a distant object, and then adjusted to a nearer one in the same direction. The position of the eyeball, of course, remains the same. It is also found that the images reflected from the cornea and from the rear surface of the lens, remain unchanged; while the image reflected from the front surface of the lens changes its position and its size in such a way as to show that this surface has been brought forward and at the same time made more convex. The eye then adjusts itself to different distances *by altering the convexity of the crystalline lens.* This change in the form of the lens is shown in Figure 141. The half A shows the form of the lens when the eye is adjusted for distant objects; and the half B, when it is adjusted for near objects.

Fig. 141.



221. *The Structure of the Retina.*—Figure 142 represents a portion of the retina highly magnified, since

Fig. 142.

the whole thickness of this membrane does not exceed $\frac{1}{80}$ of an inch. Next to the choroid coat it consists of a great number of minute rod-like and conical bodies, *c*, arranged side by side. This is the *layer of rods and cones.* The fibres of the optic nerve are all spread out between *b* and *a*. At the entrance of the optic nerve, the nerve fibres predominate, and the rods and cones are wanting. Exactly at the centre of the back of the eye, there is a slight circular depression of a yellowish hue, called the *macula lutea*, or *yellow spot.* In this spot, the cones are abundant without the rods and nerve fibres.

222. *The Action of Light on the Optic Nerve.* — *The fibres of the optic nerve are in themselves as blind as any other part of the body.* To prove this, we have only to close the left eye and with the right look steadily at the cross on this page, holding the book ten or twelve inches from the eye. The black dot will be seen quite

✠ ●

plainly as well as the cross. Now move the book slowly towards the eye, which should be kept fixed on the cross. At a certain distance the dot will suddenly disappear; but on bringing the book still nearer it will come into view again. Now it is found, that, when the dot disappears its image falls *exactly upon the point where the optic nerve enters the eye*, and where there are no rods and cones, but merely nerve fibres. Again, the *yellow spot* is the most sensitive part of the retina, though it contains no nerve fibres.

It would appear, then, that *the optic nerve is not directly affected by light, but only through the rods and cones.* These remarkable bodies are like so many finger-points, endowed with a touch delicate enough to feel the impulses of light and communicate the impression to the optic nerve.

223. *The Sensation of Light may be excited by Other Causes.* — The sensation of light may be excited by *any thing which can excite the optic nerve.* Thus an electric shock sent through the eye causes an apparent flash of light. If the finger be pressed on one side of the eyeball, a luminous image is seen. In the same way, a blow on the head may make one "see stars."

224. *The Duration of the Impression on the Retina.* — The impression made by light on the retina does not cease the instant the light is removed, but *lasts about the eighth of a second.* If the impressions are separated by a less interval, they appear continuous. Thus, if a stick with a spark of fire at the end be whirled round rapidly, it gives the impression of a circle of light. The spokes of a wheel in rapid motion cannot be distinguished.

The optical toy called the *thaumatrope* illustrates the same principle. One form of it, known as the *zoetrope*, consists (Figure 143) of a cylindrical paper box turning on an upright axis. Near the top of the box is a row of upright slits. The successive positions which a moving body assumes are represented in order upon a strip of paper; and this paper is put within the box, which is then whirled round rapidly. If we look at the pictures through the slits, they come before the eye one after another, and *the impression of each picture lasts till the next arrives, so that they all blend into one*, and the object

Fig. 143.

appears to be really going through the evolutions represented.

225. *Irradiation.* — *A white or very bright object seen against a black ground appears larger than it really is;* while *a black object on a white ground appears smaller than it really is.* The two circles given in Figure 144 illustrate this. The black one and the

Fig. 144.

white one are of just the same size, but the former appears to be the smaller.

This effect is called *irradiation.* It arises from the fact that *the impression produced by a bright object on the retina extends beyond the outline of the image.*

We have a marked case of irradiation in the new moon, which seems much larger than the old one which it is said to "hold in its arms."

226. *The Sensibility of the Retina is easily exhausted.* — When we look at a bright light, and then turn the eye towards a moderately lighted surface, a dark spot is seen; showing that the part of the retina on which the bright light fell has lost for the moment its sensibility, or *become blind.* If the bright object be of one color, the part of the retina on which its image falls becomes insensible to rays of that color, but not to those of other colors. If a red wafer be stuck upon a sheet of white paper, and viewed steadily for some time with one eye, and then the eye be turned to another part of the

paper, a greenish spot will appear of the size and shape of the wafer. The red image has made the retina blind to red light, but it has left it sensitive to the remaining colors which make up white light (208); and when red is taken from white light the combination of the other colors gives a greenish hue. If the wafer is green, the spot seen will be red.

227. *Color-Blindness.* — In some persons *the retina appears to be affected in one and the same way by different colors*, or even by all colors. The most common form of this *color-blindness*, as it is called, is an inability to distinguish red and green. Thus to many persons the leaves of the cherry-tree and its fruit seem of the same color. In some cases, persons who were color-blind without being aware of it, and who have been employed on railways, have mistaken the color of signal-lights, and serious accidents have been the result.

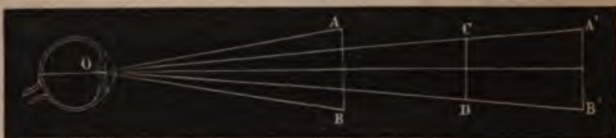
This blindness may arise either from *a defect in the retina*, or from *some peculiarity in the absorptive powers of the humors of the eye.*

228. *The Optical Axis and the Visual Angle.* — *A line drawn from the centre of the yellow spot through the centre of the pupil* is called the *optical axis.* When we look at any object we must turn the eye so as to direct this axis toward it. This gives us the *direction* of the object.

The image of an object on the retina is contained between lines drawn from the extremities of the object through the centre of the crystalline lens (217). *The angle contained between lines thus drawn* is called the *visual angle* of the object, and of course measures the length of the image on the retina. All objects which have the same visual angle form images of the same length on the retina.

229. *How we estimate the Size of a Body.*—The visual angle evidently gives us no information as to the real size of a body; for we see from Figure 145 that *the*

Fig. 145.



visual angle of a body diminishes as its distance increases, and also that *bodies at different distances may have the same visual angle, though they are not of the same size.* Thus $A\ B$ and $A'\ B'$ are the same object, but $A'\ B'$ which is farther off has the smaller visual angle. Again $C\ D$ and $A'\ B'$ have the same visual angle, but $A'\ B'$ is the larger.

Hence, *we must know the distance of a body in order to estimate its size;* but *when we know this distance we estimate its size instinctively.* Thus a chair at the other side of the room has a visual angle only half as large as that of a chair half as far from the eye, yet we cannot make it seem smaller if we try. *If we are in any way deceived as to the distance of an object, we are also deceived as to its size.*

230. *How we estimate the Distance of an Object.*—If we refer to Figure 146, we see that when the eyes are directed to a distant object, as *C*, they are turned inward but slightly; while they are turned inward considerably when directed to the nearer object *D*. *The muscular effort we have to make in turning the eyes inward so as to direct them upon an object* is one of the best methods we have of estimating its distance.

We also judge of the distance of an object from *the distinctness with which we see it.* The more obscure

it is, the more distant it seems. It is for this reason that objects seen in a fog sometimes appear enormously large.

Fig. 146.

They appear indistinct, and we cannot rid ourselves of the impression that they are far off; and hence they seem large, though they may really be small and near us.

When we know the real size of an object we judge of its distance from the visual angle; but *we judge of the distance of unknown objects mainly by comparing it with the distance of known objects.* This is one reason why the moon appears larger near the horizon than overhead, though she is really nearer in the latter case. When she is on the horizon we see that she is beyond all the objects on the earth in that direction, and therefore she seems farther off than when overhead, where there are no intervening objects to help us to judge of the distance.

231. *Why Bodies near us appear Solid.* — Hold any solid object, as a book, about a foot from the eyes, and look at it first with one eye and then with the other. It will be seen that the two images of the object are not exactly alike. With the right eye we can see a little more of the right side of the object, and with the left eye a little more of its left side. It seems to be *the blending of these two pictures* which *causes objects to appear solid.*

232. *The Stereoscope.*—The principle just stated explains the action of the *stereoscope*. Two photographs of an object are taken from slightly different points of view, so as to obtain pictures like those formed in the two eyes. These photographs are placed before the eyes in such a manner that *each eye sees only one, but both are seen in the same position.* The pictures (Figure 147) are placed at A and B. The rays of light from them fall upon the lenses m and n, and in passing through them are bent so that they enter the eye as if they came from the direction C. The lenses are portions of a double-convex lens, arranged as shown in the figure.

Fig. 147.

233. *The Laws of Distinct Vision.*—To see an object distinctly, *a clear image of it must be formed on the retina.* When an object is brought quite near the eye, it becomes indistinct; showing that there is a limit to the power which the eye has (220) of adjusting itself for different distances. The rays are now so divergent that the lens cannot bring them to a focus on the retina. *The nearest point at which a distinct image is formed upon the retina* is called the *near point* of vision, and *the greatest distance at which such an image is formed* is called the *far point.* In perfectly formed eyes, the near point is about 3½ inches from the eye, and the far point is infinitely distant. In such eyes, parallel rays are brought to a focus exactly at the retina when the eye is at rest; that is, when the crystalline lens is of its natural convexity. The pupil of the eye is so small that the rays

which fall upon it from objects 18 or 20 inches distant diverge so little that they may be regarded as parallel. *The distance of the near and far points*, however, *is not the same for all eyes.* In some cases, the near point is considerably less than $3\frac{1}{2}$ inches from the eye, while the far point is only 8 or 10 inches. In other cases, the near point is 12 inches from the eye, and the far point infinitely distant. The former are called *near-sighted* eyes; the latter, *far-sighted* ones.

It was once thought that near-sightedness was due to the too great convexity of the cornea or the crystalline lens, or of both, and far-sightedness to the too slight convexity of the same. But actual measurement has shown that *their real cause lies in the shape of the eyeball, which in far-sighted people is flattened, and in near-sighted people elongated, in the direction of the axis.* In Figure 148, the curve N shows the form

Fig. 148.

of the *normal*, or perfect eye; N', of the far-sighted eye; and N'', of the near-sighted eye. The eye is represented as at rest, and we see that the parallel rays A and A are brought to a focus on the retina of the normal eye, while only the convergent rays A' and A' are brought to a focus on the retina of the far-sighted eye, and only the divergent rays A'' on the retina of the near-sighted eye.

A'' then is the far point for the near-sighted eye, since the lens has now its least convexity; and this point must

be within 18 or 20 inches, since the rays from an object farther off are virtually parallel and cannot be brought to a focus on the retina. The *near* point must be less than for the normal eye, since the retina is farther from the lens, and therefore rays of greater divergence can be brought to a focus upon it. In the far-sighted eye, the retina is nearer the lens than in the normal eye; hence the near point is farther away. While, then, the normal eye sees distant objects distinctly without adjustment, the far-sighted eye must adjust itself to see them.

The defect of *far-sighted* eyes can be in great measure *remedied by wearing convex glasses, which help to bring the rays to a focus on the retina, and thus diminish the distance of the near point.* The defect of *near-sighted* eyes can be *remedied by the use of concave glasses, which render parallel rays divergent, and thus increase the distance of the far point.*

The *first law* of distinct vision, then, is that *a distinct image of the object must be formed on the retina.*

Again, it is well known that, as evening approaches, objects become indistinct. Here, of course, the image on the retina is distinct, but it is not brilliant enough to produce the proper effect upon the optic nerve.

The *second law* of distinct vision, then, is that *the image must be sufficiently illuminated.*

Again, some objects are so small that they cannot be seen, however much they may be illumined. Here the image is too minute to affect the optic nerve.

The *third law* of distinct vision, then, is that *the image must be of sufficient magnitude.*

234. *Old Eyes.*—As the eye grows old it *loses its power of adjustment*, the crystalline lens becoming less elastic. Hence old eyes can see distinctly only distant objects. This, however, is quite *a different thing from far-sightedness.* In the far-sighted eye, there is no lack

rer to change the convexity of the lens, but this becomes useless because of the distance of the

defect of vision caused by age can be ***remedied use of convex glasses.***

SUMMARY.

camera obscura is an apparatus by which an of an object can be formed on a screen in a dark-hamber. (218.)

eye is a camera obscura. (219.)

eye adjusts itself to light of varying intensity by the size of the pupil. (219.)

ljusts itself to various distances by changing the ity of the crystalline lens. (220.)

optic nerve is *blind.*

light acts upon the *rods and cones*, which trans-impression to the optic nerve. (222.)

thing which excites the optic nerve produces the on of light. (223.)

impression on the retina lasts a short time after ect which produced it has been removed. (224.)

impression of a bright object extends beyond the giving rise to *irradiation.* (225.)

sensitiveness of the retina for any color is readily ted. (226.)

judge of the direction of an object by the direc-the axis of the eye when turned towards it.

visual angle of an object depends on its size and e. (228.)

judge of the size and distance of an object by of its visual angle, the direction of the optical nd the distinctness of the image. (229, 230.)

Near bodies seem *solid*, because the images in the two eyes are not exactly alike. (231.)

The *stereoscope* causes pictures on a plane surface to appear solid. (232.)

In order that vision may be distinct, a distinct image must be formed on the retina, the image must be sufficiently illuminated, and must have sufficient magnitude.

Perfect eyes can adjust themselves to any distance from $3\frac{1}{2}$ inches to infinity. Near-sighted eyes can adjust themselves only to short distances, and far-sighted eyes only to long distances. (233.)

Eyes lose their power of adjustment as they grow old. (234.)

Near-sightedness and far-sightedness are due to defective forms of the eyeball. These defects and that caused by age can be partially remedied by the use of glasses. (233, 234.)

THE MICROSCOPE AND THE TELESCOPE.

235. *The Simple Microscope.*—We have seen (233) that an object must form upon the retina an image of a certain magnitude, in order to be distinctly seen. Now the magnitude of the image may be increased indefinitely by bringing the object nearer the eye; but when it is brought too near, the eye is not able to bring the rays from it to a focus on the retina. We may accomplish this, however, by the aid of *a convex lens*. Such a lens is the simplest form of a *microscope*. It is called a *microscope* (from two Greek words meaning *to see small things*) because *it enables us to see things smaller than the unaided eye can distinguish.* The more convex the lens, the nearer can the object be brought to the eye, and the larger will be the image on the retina.

236. *The Compound Microscope.*—In Figure 149, we have what is called a *compound* microscope. *M* is a

Fig. 149.

lens; *A B* is an object placed near it. An enlarged image of *A B* is formed at *a b*, and this image is viewed through the lens *N*, in the same way that an object is viewed with the single lens of a simple microscope.

The lens *M* is called the *object-glass* or the *objective;* nd *N*, the *eye-piece*. The latter is usually a combination of two lenses.

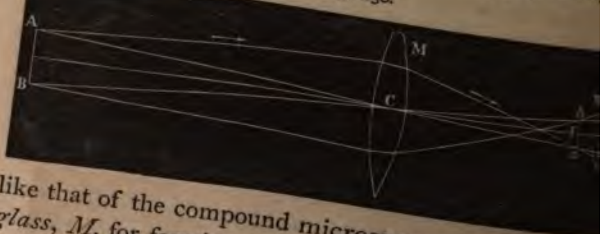
We have seen (216) that a convex lens causes the rays assing through it to meet at a *focus*. In reality, however, *this focus is not exactly the same for all the rays. hose falling near the margin of the lens meet a little oner than those falling upon its centre*, causing what called *aberration*. The more convex the lens, the reater the aberration, and the less distinct the image. his aberration can be diminished by *diminishing the ze of the lens*, so that all the rays must fall near its ntre. Hence the objective of a compound microscope, hich is a very convergent lens, is made very small.

The *magnifying power* of a microscope is commonly pressed in *diameters*. If it makes the breadth of the ject appear 50 times as great as it really is, it is said magnify 50 diameters. Of course the *surface* of th ject is increased as the *square of its diameter;* o D is case 2,500 times. The most powerful cor the the icroscopes magnify 1,500 diameters, or even ye-pi on Of course, there is no more light on this ming angle

image than there is on the object itself; hence *ject must be strongly illuminated* in order that when thus diluted may be sufficient to affect the

237. *The Telescope.* — As an object is move and farther from the eye, its image becomes smaller, until at last it may cease to affect the though the object itself may be very large. *ment for examining distant objects* is called a *te* The word is made up of two Greek words mea *see far off*. Its construction (Figure 150) is ver

Fig. 150.



like that of the compound microscope. It has an *ob glass*, *M*, for forming an image, *a b*, of the object *A* and an *eye-piece*, *N*, for examining this image. It diff from the microscope mainly in the fact that *the ima is always smaller than the object*. Since the object very distant, the rays which fall upon the object are virtually parallel; hence this glass may have a grea diameter without making the image indistinct through aberration. The larger the diameter the better, since it will collect and concentrate the more light on the image.

The *size of the image increases with its distance from the object-glass*. To make this distance as great as possible, *the object-glass has very slight convexity*. The object-glass of the *telescope* is made *as large as possible, with very slight convexity*; while that of the *microscope* is made *as small as possible, with very great convexity*. The eye-piece is the same in both

instruments. The *magnifying* is chiefly done *by the eye-piece.*

We have seen that light is dispersed when passing through a prism (204); and that a double-convex lens is somewhat like two prisms placed back to back (215). Such a lens therefore disperses the light which passes through it, giving rise to colored fringes round the image. This can be prevented by the use of a second lens made of glass of different dispersive power (204). A lens thus corrected (Figure 151) is called an *achromatic* (*colorless*) lens.

Fig. 151.

238. *The Terrestrial Telescope.* — The image in the telescope described above will be inverted. *An erect image may be obtained by using additional lenses.* The first inverted image (Figure 152) is formed at *a b.*

Fig. 152.

The lens *P* renders the rays diverging from this image parallel, and *Q* brings them to a focus again at *a′ b′*. These two lenses then act as one, and form an inverted image of the inverted image, or an erect image.

Fig. 153.

D

239. *The Opera-Glass.* — *M* (Figure 153) is the o the ject-glass, and is a converging lens. *R* is the eye-pi , on and is a diverging lens. The rays of light coming angle

the ends *A* and *B* of the object would be b
focus at *a b*, where an inverted image would
But on falling upon the eye-piece *R* they
aside, so that they enter the eye as if they
the points *a′* and *b′*. Hence the eye sees the o
erect and under a greater visual angle (228)
had been viewed directly.

The telescope invented by Galileo was an ope

THE MAGIC LANTERN.

240. In the photographic camera (Figure 139)
inverted image of the object is formed upon th
screen *E*. If *E* be a transparent picture, and a
light be sent through it from behind, an enlarg
upright image of the picture will be formed by th
in the tube *A*, and may be received upon a scree
darkened room. The nearer the picture is to th
the farther off and the larger will be the image.

An instrument for thus *projecting pictures u
screen* is called a *magic lantern.*

SUMMARY.

The *microscope* is an instrument which enables
eye to see an object at less distance than it otherw
could. With the *simple* microscope, the object is vie
ectly; with the *compound* microscope, an enlar
ge of the object is vi (235, 236.)

The *telescope* is ar t for viewing a dista
object. An image of is formed in the foc
of the object-glass an h a microscope.

The object-glass of ece, made *achromatic* by
bining lenses of from ve power. (237.)

In *terrestrial* telescopes, two or more lenses are combined so as to make the object appear upright. (238.)

The *magic lantern* forms a magnified image of an object upon a screen in a darkened room. (240.)

MIRRORS.

241. *Plane Mirrors.* — A *mirror* is a *smooth reflecting surface.* If the surface is *flat*, it is a *plane* mirror.

In Figure 154, suppose a point of light A to be in front of the plane mirror $N\ M$. The rays diverging from A, as $A\ B$ and $A\ C$, are reflected from the mirror so as to make the angle of reflection equal to that of incidence. After reflection they enter the eye O just as if they came from the point a. This point will therefore *appear to be just as far behind the mirror as A is in front of it.*

Fig. 154.

A plane mirror simply *alters the direction of the rays*, and makes them appear to come from a point as far behind the mirror as the object is in front of it. Now, as we always see an object in the direction which the rays have on entering the eye, the object will appear to be behind the mirror. *No image is formed;* for, in order to form an image, *the rays diverging from the object must be made to converge so as to meet.*

242. *Concave Mirrors.* — A concave mirror is *a portion of the inner surface of a hollow sphere.*

In Figure 155, C is the centre of the sphere of which the mirror is a part. The radii $C\ A$, $C\ B$, and $C\ D$ are perpendicular to the surface of the mirror at the points A, B, and D. *Parallel rays*, as H, G, and L, on meeting the mirror, are reflected so as to make the angle

of reflection equal to that of incidence; that is, making *C B H* equal to *C B F*, *C D G* to *C D F*, etc. Hence

Fig. 155.

the reflected rays are made to converge. If the mirror is not more than 8° or 10° in breadth, the rays will all meet at *F*, half-way between *C* and *A*. This point is called the *principal focus* of the mirror.

If rays *diverge from a point nearer the mirror than the principal focus is, they will still diverge on reflection.* If they *diverge from a point farther off than the principal focus, they will converge on reflection.*

243. *Images formed by Concave Mirrors.*—If an object be in front of a concave mirror, and outside of the principal focus, an inverted image of it will be formed

Fig. 156.

in front of the mirror (Figure 156); for the rays which diverge from it will be made to converge and meet. *The size of the image will increase with its distance from the mirror;* and *its distance from the mirror becomes greater as the mirror is made less concave, and as the object is brought nearer.*

244. *Convex Mirrors.*—A convex mirror is *a portion of the surface of a sphere.*

Such a mirror (Figure 157) *renders parallel rays divergent, and divergent rays more divergent.* Hence

Fig. 157.

an object reflected in it appears smaller than it really is.

A *concave mirror* affects the rays like a *convex lens*, and a *convex mirror* like a *concave lens.*

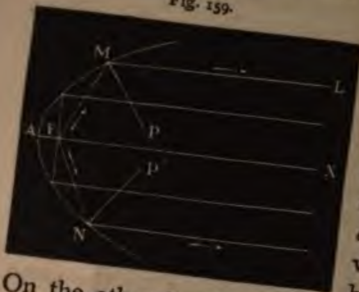
245. *The Reflecting Telescope.*—A concave mirror may be used instead of the object-lens of a telescope, as

Fig. 158.

is shown in Figure 158. The rays from an object falling upon the concave mirror *M* are reflected so as to form an image at the focus, and this image is viewed with the eye-piece *o*. *As the image is formed by reflected light*, the instrument is called a *reflecting* telescope. The ordinary telescope is called a *refracting* telescope, since *the image is formed by refracted light.*

246. *Parabolic Mirrors.* — The mirror show
ure 159 has what is called a *parabolic* surfa

Fig. 159.



therefore called
bolic mirror. T
F is called the *f*
the line *A X* the
the mirror. *If*
rays fall upon
mirror, they are r
exactly to the f
whatever may
breadth of the
On the other hand, *if a light be placed at the*
its rays will be reflected from the mirror in p
lines. This is because a parabolic surface is cur
such a way that if a perpendicular be drawn t
point, as *M*, the angle which it makes with th
M L, drawn parallel to the axis, is equal to the
it makes with the line *M F* drawn to the focus.

Parabolic mirrors are used for the lanterns plac
front of locomotive engines and in many light-hous

SUMMARY.

An object is seen reflected in a plane mirror with
enlargement, but it appears as far behind the mirror as
really is before it. (241.)

An inverted image of an object placed outside th
principal focus is formed in front of a concave mirror

A concave mirror may be used in place of the object-
glass in a telescope. (243, 245.)

In a convex mirror an object appears smaller than it
really is. (244.)

A parabolic mirror renders the rays which diverge
from its focus parallel. (246.)

HEAT.

PROPAGATION OF HEAT.

247. *Heat is Radiated in all Directions.* — When we come near a stove we feel its heat, no matter on what side of it we may be; that is, the stove *radiates* its heat in all directions.

Radiant heat, like light, *diminishes in intensity as the square of the distance increases*, and for the same reason.

248. *Heat traverses Space in Straight Lines and with the Velocity of Light.* — Heat and light come to the earth together in the sun's rays, and we have seen that these *move in straight lines* and with *a velocity of about* 190,000 *miles a second.*

249. *Luminous and Obscure Heat.* — Heat which is *radiated from a non-luminous source*, as from a ball heated below redness, is called *obscure* heat; while that *radiated from a luminous source*, as from the sun or from a ball heated to redness, is called *luminous* heat.

250. *Diathermanous Bodies.* — Some substances, as air, *allow radiant heat to pass readily through them*, and are called *diathermanous.* The term is derived from the Greek words *dia*, *through*, and *thermos*, *heat.*

If a plate of glass be held up before an iron ball heated to dull redness, a delicate thermometer held behind the plate will be scarcely, if at all, affected. If, however, a plate of rock salt be put in place of the glass, the thermometer rapidly rises. *Rock salt is the most diathermanous of all known solids*, and is to radiant heat what glass is to light.

A solution of iodine in bisulphide of carbon is wholly opaque to luminous heat, and perfectly diathermanous to obscure heat.

251. *Obscure Heat always accompanies Luminous Heat.*—If a luminous beam, as that from the lime light, be allowed to fall upon a cell with glass sides, filled with the iodine solution (250), all the luminous heat is cut off. Place a differential thermometer * behind the cell in the dark space, and we find that a beam of obscure heat is passing through the cell. Obscure is found always to accompany luminous heat; and the hotter the source, the more intense are the obscure rays. This may be shown by heating a coil of platinum wire gradually from dull redness to a white heat, and then cutting off the luminous rays by the iodine cell, and letting the obscure rays fall on a differential thermometer.

252. *Heat is Reflected and Refracted in the Same Way as Light.*—Let a beam of light fall upon a mirror, and hold one bulb of a differential thermometer in its path after it has been reflected. The luminous heat will be found to be reflected with the light. Now cut off the luminous heat with the iodine solution, and hold the bulb again in the path which the reflected beam took. It will be found that the obscure heat has also been reflected in the same path as the light.

Let the luminous beam fall upon a prism, and examine it in the same way after refraction. It will be found that both luminous and obscure heat are *refracted* like light.

253. *Heat is Dispersed in the Same Way as Light.*—Experiments have shown that radiant heat is dispersed like light on passing through a prism; and that *obscure heat is less refrangible than luminous heat.*

* A thermometer for finding the difference of temperature at two points (291).

254. *The Spectrum is made up of three Parts.*— The spectrum is found to be made up of three parts: (1) a *luminous* portion; extended, at the red end, by (2) an *obscure thermal* portion; and, at the violet end, by (3) an *obscure chemical* portion. The luminous portion is also both thermal and chemical.

Black lines (called, from their discoverer, *Fraunhofer's lines*) can be seen crossing the luminous part of the spectrum. These *dark* lines are found to be also *cold* and *chemically inactive.* Similar cold lines are found in the obscure thermal part.

255. *Calorescence and Fluorescence.*—If a jet of mixed hydrogen and oxygen be set on fire, it produces what is called the *oxy-hydrogen flame.* This flame has very little light, but its heat is intense. The radiations are mainly the obscure thermal ones. But if a small cylinder of lime be put into the flame, the light becomes most dazzling. *The obscure thermal radiations have been changed into luminous ones.* This change is called *calorescence.*

If a paper washed with a solution of quinine be held in the extreme violet end of the spectrum, the obscure *chemical* part of the spectrum becomes luminous. This *change of the obscure chemical rays into luminous ones* is called *fluorescence.*

256. *Different Solids, Liquids, and Gases absorb Heat with different Degrees of Readiness.*—If we cause rays of heat to fall upon different solids, liquids, and gases, and measure with a delicate thermometer the heat which passes through, we find that *they absorb the same kind of heat very differently.*

Again, if we use platinum wire (251) as a source of heat, we shall find that glass absorbs obscure heat better than luminous heat; and, in general, that *a given substance absorbs different kinds of heat in different*

proportions. Among gases *the best absorber of obscure heat is watery vapor.*

257. *Good Absorbers are good Radiators.* — Place a heated copper ball just half-way between two plates of tin, one of which is bright and the other coated with lamp-black; and hold the bulb of a differential thermometer against the back of each plate. The coated plate will be found to be hotter than the other, showing that it is the better absorber.

Again, place the plates against the ball, with the coated side of the blackened plate outward; and hold a differential thermometer near each to receive the heat radiated by it. It will be found that the coated plate is the better radiator.

Good absorbers always prove to be good radiators.

SUMMARY.

Heat is radiated from its source in all directions, in straight lines, with the velocity of light. (247, 248.)

Radiated heat may be luminous or obscure. (249.)

Bodies which allow heat to pass readily through them are called *diathermanous.* (250.)

Radiant heat is reflected, refracted, and dispersed in the same way as light. (252, 253.)

The spectrum is made up of three parts: (1) a luminous part; (2) an obscure thermal part; and (3) an obscure chemical part. (254.)

Calorescence is the change of the obscure thermal rays into luminous rays. *Fluorescence* is the change of the obscure chemical rays into luminous. (255.)

Different solids, liquids, and gases absorb heat very differently. (256.)

Good absorbers are good radiators. (257.)

EFFECTS OF HEAT ON BODIES.

258. *The Molecules of a Body transmit Heat to one another.*—When one end of a poker is placed in the fire, it soon becomes red hot, and the heat slowly travels from this end to the other. This heat cannot have been radiated, since radiant heat travels at the rate of 190,000 miles a second.

Fig. 160.

This *transmission of heat from molecule to molecule* of a body is called *conduction.*

259. *Different Solids conduct Heat differently.*—If several thermometer bulbs be inserted in a metallic rod, as shown in Figure 160, and one end of the bar be heated, the mercury will begin to rise in the thermometer nearest the heated end, and then in the others successively. If rods of other metals of the same length and thickness be tried in the same way, it will be found that *the metals differ widely in conductive power.* Those which are good conductors of heat are also good conductors of electricity.

260. *Liquids and Gases are Poor Conductors of Heat.*—In Figure 161, a differential thermometer (251)

Fig. 161.

is placed in a glass vessel filled with water. Heat is applied to the surface of the water by means of a dish of heated oil. If the water conducted the heat, the upper bulb would become heated sooner than the lower one, and the thermometer would at once indicate a difference of temperature between the two bulbs. But the thermometer is scarcely affected.

All liquids are poor conductors of heat; and gases are poorer ones.

261. *Heat raises the Temperature of a Body.*— The most obvious effect of the heat absorbed by a body is a rise of temperature. This rise is indicated by the sense of touch, but more accurately by a thermometer.

262. *A Body in cooling* 1° *gives out just as much Heat as it takes to heat it* 1°.—Boil half a pound of water, and plunge the bulb of a thermometer into it, and it will indicate a temperature of 212°. Remove the water from the source of heat, and add half a pound of water of a temperature of 70°. Stir the mixture a short time with the bulb of a delicate thermometer, and the temperature will be found to be 141°. The first half-pound of water has then lost 71° and the second has gained 71°; in other words, the first in cooling 1° has given out just heat enough to warm the second 1°. The same is true of all other bodies.

263. *It requires different Amounts of Heat to raise the Temperature of the same Weight of different Bodies* 1°.—Heat a piece of tin to 212° by plunging it into boiling water, and then plunge it into its own weight of water at 70°. The resulting temperature will be considerably below 141°; showing that tin in cooling

does not give out heat enough to raise the water 1°. ıt the tin in cooling 1° gives out just as much heat as it kes to raise its temperature 1°. Hence it takes more at to raise the temperature of a pound of water 1° than raise that of a pound of tin 1°. If copper be used stead of tin, the resulting temperature will be higher, ut still below 141°. It requires, then, less heat to raise e temperature of a pound of copper 1° than to raise that f a pound of water 1°, but more than it takes to raise hat of a pound of tin 1°. In this way, we find that *it akes very different amounts of heat to raise the temperature of the same weight of different substances* 1°.

264. *Unit of Heat.*—The thermometer indicates the rise of temperature in a body, but not the amount of heat required to raise the temperature. It is therefore desirable to have some unit by which the heat received by a body may be expressed. The unit usually taken is the amount of heat required to raise the temperature of a pound of water 1°. A *unit of heat*, then, is *the amount of heat required to raise the temperature of one pound of water* 1°.

265. *Specific Heat.— The amount of heat required to raise the temperature of a pound of any substance* 1°, *expressed in units*, is called the *specific heat* of that substance. Thus it requires $\frac{1}{30}$ of a unit of heat to raise the temperature of one pound of mercury 1°; and the specific heat of mercury is therefore $\frac{1}{30}$ or .033.

266. *Heat causes Solids to melt.*—Place a dish of water at the temperature of 32° and a dish of ice at the ame temperature side by side in a warm room, and hold thermometer bulb in each. The temperature of the er will gradually rise, while that of the ice will not until the whole is melted. The heat, then, which een absorbed by the ice has melted it, or changed e.

The *second* effect of heat upon a body, then, is *to change its state.*

267. *The Melting-Points of different Solids are very different.*—Ice, as we have seen, has a temperature of 32°. Mercury melts at —38°; and alcohol at a temperature lower than we have yet been able to produce. On the other hand, phosphorus melts at 111°; iron at 2912°; and charcoal at a higher temperature than we are able to produce. The melting-point of any *one* substance is, under the same circumstances, *always the same.*

Certain bodies *become soft or viscous before they melt.* Sealing-wax, when cold, is quite brittle, but when heated it first grows plastic, and finally melts. In like manner, iron before melting becomes soft in such a manner that pieces may be easily *welded* together or moulded into any form.

268. *Latent Heat of Liquids.*—If a pound of ice at 32° be mixed with a pound of water at 212°, the temperature, when the ice is melted, will be 50.5°. It has then taken 161.5 units of heat to melt a pound of ice and to raise its temperature from 32° to 50.5°, or 18.5°. It therefore takes 143 units of heat to melt a pound of ice. *Heat always disappears in melting* a solid; and this heat is called the *latent heat of fusion*, or the *latent heat of the liquid*, since it is *concealed* in the liquid.

By the latent heat of a liquid, then, we mean *the number of units of heat required to melt one pound of the substance.* Thus the latent heat of water is 143 units, which is greater than that of any other liquid.

When the liquid passes back into the solid state again, its latent heat reappears as *sensible* heat.

269. *Heat causes Liquids to boil.*—Under the ordinary pressure, if water be raised to a temperature of 212°, it begins to boil, and its temperature then remains the same until it is all converted into steam. The heat,

then, which the water absorbs changes it from the liquid to the gaseous state. Other liquids can be made to boil, but at very different temperatures. Any given liquid, under the same circumstances, always boils at the same temperature.

270. *Latent Heat of Gases.* — If a thermometer be held in the steam just over boiling water, it will indicate a temperature of 212°. Now, as water is receiving heat all the time it is boiling, this heat must be latent in the steam. The latent heat of different gases is found to vary greatly. The latent heat of steam and watery vapor is greater than that of any other gas or vapor, hydrogen alone excepted.

271. *The State of a Body depends upon its Temperature.* — When a solid is heated, its temperature rises till it reaches the melting-point, where it remains stationary until the solid is melted. It then rises again until it reaches the boiling-point, where it again remains stationary until the liquid is converted into a gas. When a gas is sufficiently cooled, it goes through the same changes in the reverse order.

It is because different substances have very different boiling-points that they can exist in nature, some as solids, some as liquids, and some as gases.

272. *The Boiling-Point of Water falls as the Pressure on its Surface diminishes.* — Fill a flask two-thirds full of water, boil it for some time, cork it tightly, removing it at the same time from the source of heat, and invert it, as shown in Figure 162. Pour cold water upon the flask, and it begins to boil again.

At first the upper part of the flask is full of steam, whose elastic force causes it to press upon the water. When cold water is poured upon the flask, this steam is condensed, the pressure is diminished, and the water boils, though at a lower temperature.

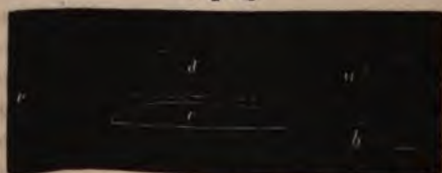
The *height of a mountain* can be estimated quite accurately from *the difference between the boiling-points at its summit and at its base.*

Fig. 162.

Steam occupies very much more space than the same weight of water, and there is no cohesion among its molecules (22). When, therefore, water boils, both the cohesion of the liquid and the pressure of the atmosphere must be overcome, since both of these tend to keep the molecules together. Hence, *when either the cohesive force or the external pressure is changed, the boiling-point will also change.*

273. *The Spheroidal State.* — If two or three drops of water be poured into a red-hot metallic cup, they gather into a globule, which runs about without boiling. The water is now said to be in the *spheroidal state.*

Fig. 163.



Turn a cup *c* bottom up (Figure 163), heat it to redness, and carefully put a drop of water *d* upon it with a

opping-tube. Place behind the drop a platinum wire *b*, heated to a white heat by a battery. With the eye *e*, the platinum wire can be seen between the drop and e cup, showing that *the drop does not touch the cup.*

As soon as the drop comes near the heated cup, *steam generated beneath it, and acts like an elastic spring lift the drop from the surface.* As the cup cools, his spring gives way, and the water, on touching the urface, is suddenly converted into steam. Boiler explosions are probably often caused by this sudden change rom the spheroidal state to steam.

274. *Evaporation.*—If water is exposed in an open vessel at the ordinary temperature, it gradually disappears, *passing off in the form of vapor.* This vapor is formed *slowly* and *only at the surface;* while, in *boiling*, steam is formed *rapidly* and *throughout the liquid.* Water is thus evaporated into the atmosphere *at all temperatures*, but *more rapidly as the temperature rises.*

275. *Condensation.* — *A gas condenses at the same point at which its liquid boils;* and, as pressure raises the boiling-point, it also raises the point at which a gas will condense. Under the combined action of pressure and cold, almost every known gas has been liquefied.

276. *Freezing-Mixtures.* — When a solid melts, or a liquid evaporates, a large amount of heat is rendered latent. Advantage is taken of this fact to obtain an artificial reduction of temperature. One of the most common freezing-mixtures is composed of *salt and pounded ice.* The substance to be frozen is placed in a small vessel which is put in a larger one and packed round with this mixture. *The ice rapidly melts, and in doing so absorbs a large amount of heat, thus reducing the temperature* of the inner vessel.

A much greater degree of cold is obtained by the rapid evaporation of a liquid than by the melting of a solid.

If solid carbonic acid be mixed with ether, it evaporates very rapidly. By means of such a mixture, 20 or 30 pounds of mercury may be readily frozen. If the mixture be placed under an exhausted receiver, the evaporation is greatly quickened. Faraday thus reached a temperature of $-166°$ F.

277. *Solids are expanded by Heat; but different Solids expand unequally for the same Rise of Temperature.* — We have already learned (6) that solids are expanded by heat. If now a bar of iron and one of copper be riveted together and then plunged in boiling water, so that the temperature of both may be raised to the same point, the compound bar will become curved, the copper being the convex side. This is because copper is expanded more than iron for the same rise of temperature. Scarcely any two solids are expanded alike by heat.

278. *Liquids are expanded by Heat; but different Liquids expand unequally for the same Rise of Temperature.* — Fill a test-tube with water, and then close it with a rubber cork through which passes a fine glass tube. Plunge the test-tube in boiling water, and the liquid will rise in the tube; showing that it has been expanded by heat.

Fill a second test-tube with alcohol, and plunge both into boiling water. The alcohol will rise higher in the tube than the water will, showing that it is expanded more by the heat. Different liquids, then, *expand unequally for the same rise of temperature.*

279. *Gases are expanded by Heat, and different Gases expand equally for the same Rise of Temperature.* — Close a pint flask with a cork through which passes a bent tube, and connect the tube with a jar inverted over water. Plunge the flask into boiling water, and bubbles of air rush over into the jar. All gases are thus expanded by heat.

Fill now the same flask with hydrogen, oxygen, or any other gas; connect it with the same jar as before, and again plunge the flask into boiling water. Precisely the same amount of gas will pass over as at first.

Solids, liquids, and gases are expanded by heat; solids and liquids unequally, and gases equally, for the same rise of temperature.

280. *Convection.* — Since the molecules of liquids and gases are free to move, their expansion, when they are heated unequally in different parts, will create *currents.* The unexpanded and heavier portions will tend to displace the lighter ones and to compel them to rise. As these heavier portions become heated, they in turn tend to rise and give place to colder portions; and so on. *These currents tend to distribute the heat*, and this mode of distribution is called *convection.*

281. *Convection of Liquids.* — In Figure 164, we have a glass beaker filled with water heated by a lamp below. A little sawdust is added to the water, and its motions show that a current is passing up the centre of the vessel and down at the sides, as indicated by the arrows in the figure. Each molecule is thus seen to come to the bottom to get heated, and then to return to the surface. It is in this way that water, which is a bad conductor, is *readily heated when the heat is applied below.*

Fig. 164.

282. *Oceanic Currents.* — Oceanic currents are produced by convection. The temperature of the sea in the tropics is about 50° higher than at the poles, and the

specific gravity of the water is therefore much less. To restore the equilibrium, the warmer and lighter water of the tropical regions flows towards the poles, and the colder and denser water of the polar regions flows towards the equator. If the whole earth were covered with water of the same saltness, we should everywhere have a surface-current from the equator towards the poles, and an under-current from the poles towards the equator. But owing to the obstructions offered by the land and by the inequalities in the bed of the ocean, and to the different degrees of saltness, and therefore of density, in different parts of the sea, these two great currents are broken up into innumerable minor currents and counter-currents.

The most remarkable of these currents is the Gulf Stream, which issues from the Gulf of Mexico, and crossing the Atlantic in a north-easterly direction, washes the western coast of Europe.

187. *Convection of Gases.*—If a lighted candle be held in the crack of a door which opens from a w
into a cold room, the flame will be blown outward a
top of the door and inward at the bottom, while hal
up it will burn steadily. A current of cold air is pa
into the room at the bottom, driving out a curr
warm air at the top.

It is mainly by convection that the air in a r
heated. The air near the stove is heated and exp
and then forced upward by the current of colder

When a building is heated by a furnace, this is
in the cellar and encased in brick-work or in shee
The space between the fire-pot and the casing i
nected by the air-box with the outer atmosphe
by flues or pipes with the rooms to be heated.
air about the fire-pot first becomes heated, and is
up through the pipes by the cold air from withou

4. *The Relation of Water to Heat and Climate.* Vater, from its high specific and latent heat, has a ked influence on climate. It makes the transition ı winter to summer and from summer to winter more lual. In the spring, when the snow begins to melt, a ;e amount of heat is absorbed from the air and rened latent. After the snow and ice are all melted, such he specific heat of water that it requires a great deal heat to raise its temperature. In the fall, on the other nd, as the water cools down and freezes, it gives out the heat which it had absorbed in the spring.

285. *The Irregular Expansion and Contraction of Vater.* — If water at the temperature of 39° be either armed or cooled, it expands. This temperature is ence called the *point of maximum density* of water.

We can now understand why water often bursts the ipe or vessel in which it freezes. *Water is the only quid which has such a point of maximum density*, nd there are but very few substances which expand rhen they become solid. Iron is one, and it is owing o this property that it is so well adapted for castings. As it solidifies, it expands so as completely to fill the nould.

This irregular expansion of water is of the greatest importance. Before freezing it begins to grow lighter, so that the freezing begins at the surface; and the ice, being lighter still and also a poor conductor of heat, floats upon the water and keeps it from freezing very deep. If water continued to contract as it cooled, it would begin to freeze at the bottom, and during the winter our lakes and rivers would become solid masses of ice. This would be fatal to all animal life in the water; and, as water is a very poor conductor of heat, it would melt only to the depth of a few feet during the summer.

286. *Heating by Steam.*—It is
to warm buildings by steam. Pipes
through the rooms to be heated, an
boiler again. The steam passes fr
these pipes, where it is condensed
water to the boiler. Now every pou
verted into steam in the boiler takes
of heat, and every pound of steam wh
the pipes gives out the same amount
rooms. The water thus acts as carrier
the furnace and the room where it is want

287. *A Hot-House is a Trap to catch*
A hot-house is covered with glass. Now
that luminous heat, like that from the sun,
through glass, while obscure heat can
through it at all. As, therefore, the su
down upon the roof of a hot-house, they
trate the glass; but, when they fall upon
and furniture within, they are radiated back
heat, and are unable to make their way t
glass except by the slow process of conducti
because the sunbeams are thus caught in a trap
temperature inside a hot-house on a sunny day
higher than outside.

SUMMARY.

Heat is transmitted from molecule to molec
bodies by *conduction*. Liquids and gases are poor
ductors. (258, 260.)

The heat which a body absorbs is partially use
raising its temperature. (261.)

A body in cooling 1° gives out just as much heat a
takes to warm it 1°. (262.)

It takes a different amount of heat to raise the temperature of the same weight of different substances 1°. The amount of heat required to raise the temperature of one pound of water 1° is called a *unit of heat*. The amount of heat required to raise the temperature of one pound of any substance 1°, expressed in thermal units, is called its *specific heat*. (263–265.)

The heat which a body absorbs is sometimes used in changing its state. (266.)

The melting and boiling points are the same for the same substance under the same pressure; but those of different substances are different. (267, 269.)

When a substance melts or boils, a certain definite amount of heat is rendered *latent*.

The latent heat of *water* is higher than that of any other liquid; and that of *steam* is higher than that of any other vapor. (268, 270.)

The boiling-point of water is raised by increasing the pressure. (272.)

When water is put into a red-hot vessel, it is prevented from coming in contact with the heated surface by a layer of steam, and is said to be in the *spheroidal state*. (273.)

Liquids evaporate at all temperatures, but more rapidly as the temperature rises. Vapors condense at the same point as that at which their liquids boil. (274, 275.)

The heat absorbed by a body is used partially in pushing the molecules apart, or *expanding* it. Different solids and liquids expand unequally, and different gases equally, for the same rise of temperature. (277–279.)

When a gas or a liquid is heated beneath its surface, currents are produced which distribute heat by *convection*. It is in this way that the Gulf Stream and other oceanic currents are produced. (280–283.)

... the freezing-point is ...
... which is the one in ...
... and England the *freezing-* ...
... the two being divided into 180 equal pa...
... These equal divisions are continued abo...

ling-point and below the freezing-point; but not be-
—38° nor above 576°, since *mercury freezes* at the
mer point and *boils* at the latter.

On the *Centigrade* scale, which is the one commonly
ed in France, and the one generally preferred by scien-
ic men, *the freezing-point is marked* 0, *and the boil-
g-point* 100. 5° of this scale, then, are equal to 9° of
e Fahrenheit scale.

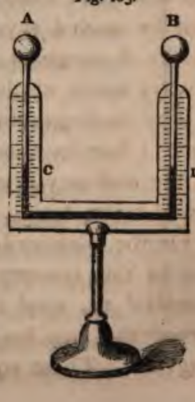
A third scale, known as *Reaumur's*, is in general use
Germany. On this scale *the freezing-point is marked*
, *and the boiling-point* 80.

289. *The Alcohol Thermometer.* — When tempera-
res below —38° are to be measured, alcohol is used
stead of mercury. An alcohol thermometer is not,
owever, so accurate as a mercurial one.

290. *The Air Thermometer.* — There are various
ays of measuring temperatures above the boiling-point
f mercury, but the best is by means of the *air ther-
mometer.* The expansive force of air is very regular
or all known temperatures, but it expands so rapidly
that to measure the ordinary range of temperatures
would require too long a tube.

The expansion of the air in the tube is *indicated by the movement of a column of liquid upon which it acts.*

Fig. 165.



291. *The Differential Thermometer.* — This instrument shows *the difference in temperature between two neighboring substances or places.* In the one invented by Leslie (Figure 165), two bulbs, *A* and *B*, filled with air, are connected by a bent tube. A little colored liquid fills the lower part of this tube, and rises to the levels *C* and *D* when both bulbs are

of the same temperature. But should A
than B, since air expands very much f
temperature, the column of liquid will
at C and made to rise at D; and this
reversed when B becomes warmer than A
difference of temperature is therefore ind
Sulphuric acid, or some other liquid which
is used in the tube.

292. *Effect of Temperature upon Meas*
—The rate of a clock depends upon the ti
its pendulum vibrates, and that of a watch u
in which its balance-wheel oscillates. No
change of temperature alters the length of a
it likewise alters its time of vibration (106).
the temperature, the more slowly does it v
like manner, a change of temperature, by a
dimensions of the balance-wheel of a watc
force of the spring, will cause it to vibrate m
in hot weather than in cold.

Fig. 166.

293. *Graham's Mercurial Pendulu*
first attempt to compensate for change
in a pendulum was made by Graham, an
clockmaker. The rod of his pendulum
166) was made of glass, to the lower end
was attached a cylindrical vessel contain
cury. As the glass rod expands by he
bottom of the vessel which contains the m
will of course be carried farther from the
of suspension; but since the mercury resti
this base expands upwards, its centre of g
is raised, or brought nearer the point of su
sion. *The lowering of the centre of gra*
due to the expansion of the glass, may thu
counteracted by the rise of the same, due to
expansion of the mercury.

94. *Compensation Balance-Wheel.* — The balance-
eel of a watch is sometimes made, as in Figure 167,
t with one continuous rim, but with
broken rim of several separate
ieces, all of which are fixed at one
nd and free at the other, the free
nds being loaded; and each piece
s composed of two metals, of which
ne more expansible is placed outside.
On a rise of temperature, then, *the
oaded ends will approach the centre.* This is made *to
counteract the effect produced on the rate of the watch
by the expansion of the wheel, which carries the cir-
cumference farther from the centre.*

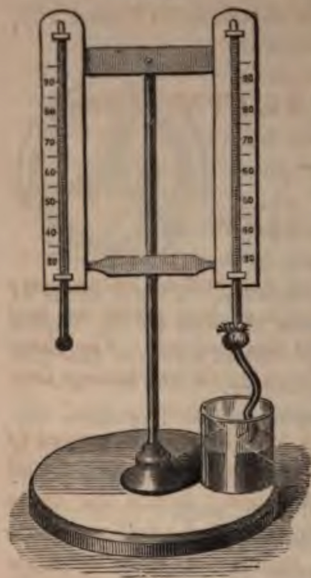
Fig. 167.

295. *Other Effects of Expansion.* — The force exerted by solids in contracting or expanding, or by liquids in expanding, is very great. If a strong vessel be entirely filled with a liquid and then sealed tightly, the vessel will burst if considerably heated.

In the arts it is of great importance to bear in mind the intensity of this force, sometimes with the view of guarding against its action, and sometimes in order to make it useful. Thus, bars of furnaces must not be fitted tightly at their extremities, but must at least be free at one end. In making railways, also, a small space must be left between the successive rails. For a similar reason water-pipes and gas-pipes are fitted to each other by telescopic joints.

296. *Wet and Dry Bulb Hygrometer.* — A *hygrometer* is *an instrument for measuring the amount of moisture in the air.* The one invented by Mason consists of two thermometers (Figure 168) placed side by side, one having a dry bulb and the other a bulb covered with muslin, kept moist by means of a string dipping in water. The wet bulb is chilled by the evaporation of

Fig. 168.



the water from it, sin
evaporation renders s
its heat latent. *The
the air, the more
the evaporation,* an
*greater the differen
tween the readings
two thermometers.*

297. *Edson's Hygr*
— This is an improved
of Mason's hygromet
differs from all other
meters in having a di
pointer, *showing at a g
the temperature, the
of humidity, the ab
amount of vapor in
cubic foot of air,* an
dew-point.

The *dew-point* is *th
perature at which the moisture of the air begin
deposited as dew.*

SUMMARY.

The thermometer is used to measure tempe
The thermometer *scales* most used are *Fahren*
the *Centigrade*, and *Reaumur's*. (288–290.)

The *differential* thermometer serves to measu
difference of temperature at two places. (291.)

The expansive power of heat may be made to
late the rate of clocks and watches. (292–294.)

The *hygrometer* and *hygrodeik* are instrumen
measuring the amount of moisture in the air. (296,

ELECTRICITY.

MAGNETISM.

298. *Magnets.*—If we bring one end of an ordinary bar magnet in contact with a pile of iron tacks, we find that some of the tacks cling to the magnet. *The force residing in a magnet and shown by its attracting iron* is called *magnetism.*

There is a certain iron ore which has the power of attracting iron. This ore seems to have been first found near Magnesia, a city of Asia Minor; hence the name *magnet.* Natural magnets are called *loadstones* (more properly *lodestones*), that is, stones that *lead* or draw iron.

299. *The Power of a Magnet resides chiefly at the Ends.*—If a small iron ball, suspended by a string, be moved alongside a bar magnet, it is scarcely attracted at

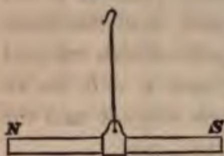
Fig. 169.

the middle of the bar. As it approaches either end, it is attracted more and more, and *near the ends the attraction is much the strongest.*

Lay a piece of stiff drawing-paper upon a strong magnetic bar, and strew fine iron-filings over it. The particles of iron (Figure 169) arrange themselves in *lines radiating from the poles*, called *lines of magnetic force*, or *magnetic curves*.

300. *The Forces at the Ends of a Magnet act in Opposite Directions.* — Suspend a bar magnet by a string (Figure 170) so that it can turn freely. Bring one end of a bar magnet near one end of the suspended magnet, and the latter is drawn towards it. Reverse the ends of the bar magnet, and the end of the suspended magnet is repelled. This shows that *the forces at the ends of a magnet act in opposite directions.*

Fig. 170.



The ends of the magnet, or *the points where the opposite forces reside*, are called *poles*.

301. *The Magnetic Needle.* — *A bar magnet poised or suspended so as to turn freely* is called a *magnetic needle*. *One of its poles will always point to the north*, and is called the *north pole*. The opposite pole is called the *south pole*.

302. *The Earth acts like a Magnet.* — If a small needle which is free to move horizontally be placed upon a bar magnet, its south pole will always point towards the north pole of the latter. If a small *dipping needle*, that is, *a needle which is free to move vertically*, be placed above the middle of a bar magnet, it stands parallel with the bar magnet. If it be moved towards the north pole of the magnet, the south pole dips more and more towards the magnet. If it be moved from the centre of the bar magnet towards the south pole, its north pole dips in the same way.

Now, a magnetic needle (301) points north and south

when held above the earth. A dipping needle near the equator stands horizontally; when carried north from the equator, its north pole dips towards the horizon; and when carried south from the equator, its south pole dips.

We see, then, that *the earth acts upon a magnetic needle like a magnet whose poles are near the poles of the earth.*

303. *Like Poles of Magnets repel and unlike Poles attract each other.*—Bring the north pole of a bar magnet near the north pole of a needle, and the latter will be repelled. Bring the south pole of this magnet near the north pole of the needle, and it will be attracted. The experiment with the bar magnet and the dipping needle (302) also illustrates this law.

304. *Magnetism is developed in Iron or Steel by Induction.*—When a piece of soft iron is brought in contact with the pole of a magnet, it will attract other pieces of iron, showing that *magnetism is developed in the iron by contact with the magnet.* Magnetism can be developed, or *induced*, in a piece of steel in the same way. *The iron loses its magnetism as soon as it is taken away from the magnet, while the steel retains it.* The iron or steel need not come in actual contact with the magnet. Magnetism will be induced in it, if it merely be brought *very near* the pole.

Fig. 171.

305. *Forms of Magnets.*—Ordinary magnets are made of steel. When *straight*, they are called *bar magnets;* when *bent into the shape of the letter U*, they are called *horseshoe magnets.* *Several bar or horseshoe magnets connected* (Figure 171) constitute a *magnetic battery.*

SUMMARY.

The force which enables a magnet to attract iron is called *magnetism*. (298.)

This force resides chiefly at the ends, or *poles*, of a magnet. It radiates from these poles in curved lines, called *lines of magnetic force, or magnetic curves*. (299, 300.)

The forces at the poles of a magnet act in opposite directions. (300.)

The earth acts upon a needle like a magnet. Its magnetic poles are situated near the poles of its axis. (302.)

Like poles of magnets repel, and unlike poles attract, each other. (303.)

A magnet can develop magnetism in iron or steel by *induction*. Soft iron loses its magnetism as soon as it is withdrawn from the influence of the magnet, while steel retains its magnetism permanently. (304.)

VOLTAIC ELECTRICITY.

306. *The Voltaic Pair.*—If a strip of amalgamated zinc (zinc which has been immersed in mercury) and another of copper be placed in a cup of dilute sulphuric acid, no action takes place so long as the zinc and copper are not connected. If we join the plates by means of a wire, bubbles of hydrogen gas at once appear at the copper plate, and the acid begins to dissolve the zinc plate.

If a small magnetic needle be held near the wire when the plates are connected (Figure 172), the needle will

ned aside, showing that there is new *force* in the wire. This rce is called *electricity;* and, as ns to *flow* through the wire, it is in this case *the electric current.* roduced by the chemical action n the acid and the zinc.

Fig. 172.

plates thus connected form a *pair* or *cell.* The *zinc* is the *active* plate, and the *copper ssive* plate. The passive plate n made of other substances.

active plate is also called the *negative pole*, and *ssive plate* the *positive pole* of the cell. *What- onnects the poles* is called the *circuit.*

electric current is always assumed to flow *from ssive plate, or positive pole, through the wire to tive plate, or negative pole.*

Bunsen's Cell. — When the above voltaic cell is ion, bubbles of hydrogen collect upon the passive so as nearly to cover it. This prevents contact be- the plate and the liquid, and res with the chemical action of ll.

Fig. 173.

Bunsen's cell this collection of gen is prevented by surround- e passive plate with strong nitric which takes up the hydrogen. cell (Figure 173) consists of the ing parts: a large earthen or cup; a piece of zinc rolled into nder and open down one side; a s porcelain cup, small enough to side the zinc cylinder; and a of coke carbon, small enough to stand inside the

porcelain cup. The larger cup is filled with dilute sulphuric acid, and the smaller cup with the strongest nitric acid.* The carbon is the passive plate.

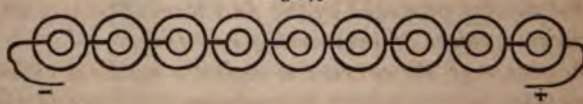
In *Grove's cell*, a strip of platinum is used for the passive plate, instead of carbon. In other respects it is essentially the same as Bunsen's.

308. *Daniell's Cell.* — This cell is shown in Figure 174. The outer vessel is of copper, and serves as the passive plate. Inside this is a vessel of porous earthen-ware, containing a rod of zinc. The space between the copper and the porous cup is filled with a solution of blue vitriol, which is kept saturated by crystals of the salt lying on a perforated shelf. The porous cup is filled with dilute sulphuric acid. The porous partition keeps the fluids from mingling, but does not hinder the passage of the current. The blue vitriol in contact with the passive plate serves to take up the hydrogen.

Fig. 174.

309. *The Electric Battery.* — *Several cells joined together* constitute a *battery*. There are two ways in which the cells may be joined: (1) *the zinc of the first cell may be joined to the carbon of the second, and the zinc of the second to the carbon of the third, and so on throughout, and the free carbon of the first cell joined to the free zinc of the last by a wire*, as in Fig-

Fig. 175.



* Instead of nitric acid, we may use a mixture of equal parts of strong sulphuric acid and a concentrated solution of bichromate of potash.

re 175; or (2) *the zincs may all be joined together, nd the carbons all joined together, and then the zincs nd the carbons joined by a wire*, as in Figure 176.

310. *Quantity and Intensity.* — Arrange a battery of aree cells according to the first method, and connect the oles by a short, thick copper wire, which passes over a eedle, and observe how much the needle is turned aside, r *deflected*. Then arrange the same cells according to he second method, and connect the zinc and carbon by he same wire; and *the needle will be deflected more* han in the former case. When the battery, then, is rranged according to the *second* method, *the current as the greater power to deflect the needle.*

Fig. 176.

If now the cells be again arranged in the *first* way, and a piece of *fine steel wire, two or three feet long*, be put into the circuit, *the needle will be deflected considerably less* than when the circuit is completed with the *short, thick copper wire;* showing that *the current is resisted in passing through the fine wire.* If the same piece of fine wire be put into the circuit when the battery is arranged according to the *second* method, *the needle will be deflected considerably less than* before; showing that the current produced by the *first* form of battery *has the greater power of overcoming resistance.*

The power of the current to deflect a needle is called its *quantity*, and its *power to overcome resistance in the circuit* is called its *intensity*, or its *tension.*

The *first* form of the battery develops electricity *of the greatest tension*, and is called a *battery of tension*, or

Fig. 177.

intensity battery; while the *second* form of the battery develops electricity *in the greatest quantity*, and is called a *battery of quantity*, or *quantity battery.*

When electricity in considerable quantity and of considerable tension is required, *the two methods of arranging the battery are combined*, as represented in Figure 177.

311. *Conductors and Non-Conductors.* — If a piece of glass, sealing-wax, or dry wood be put into the circuit, no current passes. *Substances which will not allow the electric force to pass through them* are called *non-conductors;* while *those through which it passes freely* are called *conductors.* Metals are generally good conductors. Copper is one of the best conductors, and is generally used for transmitting the electric current.

When the circuit is composed entirely of conductors, it is called a *closed* circuit; *when there is a non-conductor in any part of the circuit,* it is called an *open* circuit.

312. *The Rheotome and the Rheotrope.* — *An instrument for breaking the current* is called a *rheotome*, a name derived from two Greek words, and signifying *current-cutter.* *An instrument for changing the direction of the current* is called a *rheotrope;* that is, a *current-turner.* These two instruments are often combined in one.

313. *A Magnetic Needle tends to place itself at right angles with a Wire through which a Current is flowing.* — If the current be made to flow over a needle from its north end to its south end, the north pole of the needle will turn to the *left* hand of an observer who is facing that pole. If it be made to pass over the needle

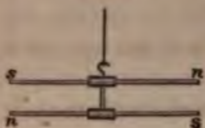
from its south pole to its north, its north pole will turn to the *right*. If it be made to flow *under* the needle, the north pole will turn in just the opposite direction. We see, then, that the needle always tends to place itself *at right angles to a wire through which a current is flowing*.

314. *The Rheoscope, or Galvanometer.* — *An instrument used for detecting or measuring a current* is called a *rheoscope*, or a *galvanometer*. The first name means a *current-examiner;* the second, a *measurer of galvanism*. Current electricity is often called *galvanism*, from its discoverer, Galvani.

If the magnetic needle used to detect the electricity (306) moves over a graduated arc, it will be found to move a greater number of degrees when the current passes entirely round it, than when it merely passes over it or under it. The effect is the same as if two currents of equal strength were passing over or under the needle, and both in the same direction. Every time, therefore, that the wire conducting the current is coiled round the needle, the effect of the current is multiplied. *A current which is too weak to deflect the needle by simply passing over or under it, may be made to deflect it decidedly by coiling the conducting wire many times round the needle.*

315. *The Astatic Needle.* — When a single needle is deflected by the current, the *directive action of the earth*, which tends to make the needle take a north and south position, offers a resistance to the deflection. In order to neutralize this directive action, *two needles of equal magnetic strength are fastened together, so that the north pole of one faces the south pole of the other*, as in Figure 178. Since the earth will pull each end of such a compound needle towards the north and towards the south with equal strength, it v

Fig. 178.



have no tendency to point north and south. This needle is called an *astatic needle* (from a Greek word meaning *unsteady*); that is, one *having no directive power*. An *astatic galvanometer* is one in which the needle is of this kind.

316. *The Resistance of Conductors.*—It has been proved that *the resistances of wires of the same material and of uniform thickness to the current are in the direct ratio of their lengths, and in the inverse ratio of the squares of their diameters.* Thus a wire of a certain length offers twice the resistance of its half, thrice that of its third, and so forth. Again, wires of the same metal, whose diameters are in the ratio of 1, 2, 3, etc., offer resistances which are to each other as 1, $\frac{1}{4}$, $\frac{1}{9}$, etc. Therefore, the longer the wire, the greater the resistance; the thicker the wire, the less the resistance. The same holds true of liquids, but not with the same exactness.

SUMMARY.

A *voltaic pair* or *cell* consists of two plates, usually of metal, immersed in a liquid which will act chemically upon one of them. The plate acted upon is called the *active* plate, the other the *passive* plate.

The two plates are called the *poles* of the cell; the passive the *positive* pole, and the active the *negative* pole. That which is employed to connect the poles is called the *circuit*. (306.)

A force called *electricity* resides in a wire which connects the poles. Since this force seems to flow through the wire, it is called a *current*. We always consider the

current as starting from the positive pole, and passing to the negative pole. (306, 311.)

When two or more cells are connected, the apparatus is called a *battery*.

The carbon of one cell may be connected with the zinc of the next, and so on throughout; or the carbons may all be connected, and also all the zincs. In the first case, the free zinc of the first cell and the free carbon of the last are the poles of the battery; in the second, the united carbons constitute one pole, and the united zincs the other. (309.)

The power of the current to turn a needle is called its *quantity;* its power to overcome resistance, its *intensity.*

The first form of battery gives electricity of greater *intensity* than the second form; while the latter gives electricity of greater *quantity* than the other. (310.)

Substances which allow the current to pass readily through them are called *conductors;* those which will not allow it to pass are called *non-conductors.* A *closed* circuit is made up entirely of conductors. If there is a non-conductor in the circuit, it is said to be *open.* (311.)

An instrument for breaking the current is called a *rheotome;* an instrument for changing the direction of the current, a *rheotrope.* (312.)

A magnetic needle tends to place itself at right angles to a wire through which a current is passing. The direction in which the needle turns depends on the direction of the current, and upon the position of the needle with reference to the wire. (313.)

An instrument for indicating and measuring the current is called a *rheoscope*, or *galvanometer.* (314.)

The resistance to the deflection of the needle caused by the magnetic attraction of the earth is neutralized in the *astatic* needle, which is therefore more sensitive to the action of the current. (315.)

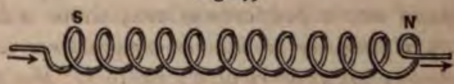
The effect of the current upon a needle is multiplied by coiling the wire round the needle. (314.)

The resistances of wires of the same material and thickness are directly as their lengths, and inversely as the squares of their diameters. (316.)

ELECTRO-MAGNETISM.

317. *The Current can make Iron magnetic.*—If a part of the wire of the circuit be wound into a coil, a piece of soft iron placed inside this coil *becomes strongly magnetic while the current is passing*, and is called an *electro-magnet*. The *coil* is called a *helix*. When the current passes through the coil *in the direction of the hands of a watch*, the end at which it enters will be a *south* pole, as in Figure 179; so that, *by*

Fig. 179.



reversing the current, the poles of the electro-magnet will be reversed.

When the current is broken, the soft iron instantly loses its magnetism. A steel rod retains its magnetism after the current is broken. If the wire is wound around the iron in several layers, the strength of the magnet is greatly increased.

Fig. 180.

The strongest electro-magnets are of the horseshoe form. *They far exceed ordinary magnets in power.* Small electro-magnets have been made which support 3,500 times their own weight, and large ones which hold up a weight of 2,500 pounds. These magnets are much stronger when pro-

vided with a *keeper*, or *armature;* that is, *a piece of soft iron to connect the poles*, as in Figure 180.

318. *The Wire through which a Current is passing is a Magnet.*—If the current be sent through a coil such as is shown in Figure 181, and the end of a rod of soft iron be brought near the opening in the centre, it is at once drawn into the coil. Coils have been made which would draw up a weight of 600 pounds.

Fig. 181.

If the wire joining the poles of a battery is brought in contact with fine iron filings, they adhere to the wire; showing that *any wire through which the current is flowing is magnetic.*

319. *Electricity as a Source of Mechanical Power.*—All the electro-magnetic machines which have been invented for doing work, *depend on the property of an electro-magnet to acquire or to lose its magnetism when the current flows or is interrupted; or to reverse its poles when the direction of the current changes.*

Page's rotating machine (Figure 182) illustrates one method of making the electric force do work. It consists of a horseshoe magnet, in the axis of which is an upright shaft. To this a piece of soft iron is fixed, with its ends facing the poles of the magnet. The soft iron is surrounded with a coil of copper wire, so that it is an electro-magnet. The ends of the wires of the coil are fastened to two metallic strips, which are attached to the shaft. The current comes to the coil through two springs which

Fig. 182.

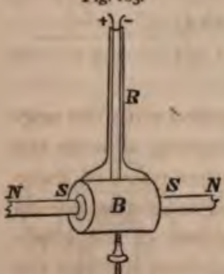
ne
cted
h the

press against these strips, and which act as a rheotrope to reverse the current when the shaft has turned half-way round.

The machine is so arranged that, at starting, the poles of the two magnets facing each other are of the same kind. They therefore repel each other, and when the shaft is once started, they send it around a quarter of the way; then unlike poles begin to approach each other, and their attraction causes the shaft to complete half a rotation. The current then changes its direction, the poles of the electro-magnet are reversed, and like poles again face each other and are repelled. The rotation is kept up by the self-acting rheotrope. The shaft may be made to rotate 2,000 times a minute, causing 4,000 changes of polarity in that brief time.

320. *Electric Clocks.* — The electric force has also been used to regulate the movements of clocks, called *copying clocks.* They are of the usual construction, except that the pendulum balls are hollow coils of copper wire, which become magnetic when a current is sent through them. In Figure 183, R represents a part of the rod, and B the ball, of such a pendulum. Permanent magnets, $N S$ and $S N$, are fastened against the sides of the clock-case opposite the ends of the coil B, with like poles towards the coil. The hollow of the coil, as it swings, can pass a little way up the length of each magnet. If the south poles of the magnets are turned towards the coil, as in the figure, and a current is sent through the one end of the coil becomes a north pole, which is [illegible]d by the magnet near it, and the other end a [illegible]le, which is repelled by the magnet near it.

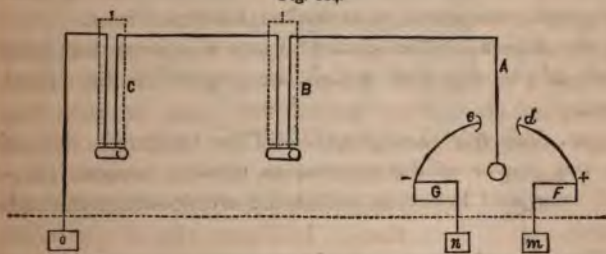
Fig. 183.



This attraction and repulsion both tend to send the coil in one direction. If, now, at the instant that *B* is drawn to one side, the direction of the current is changed, the poles of the coil are reversed, and it is carried to the other side. The pendulum thus *vibrates every time the current is reversed.* This is done by means of a *regulating clock.* Every time the pendulum of this clock vibrates, the current is reversed; so that the pendulums of all the copying clocks vibrate exactly at the same rate as the pendulum of the regulating clock.

Figure 184 shows one of the ways in which the pendulum, *A*, of the regulating clock can change the direction

Fig. 184.



of the current. The spring *e* is connected with the negative pole of the battery *G*, and the spring *d* with the positive pole of the battery *F*. The other poles of these batteries are connected with the plates *m* and *n*, buried in the earth. *B* and *C* are the pendulums of the copying clocks. When the regulating pendulum touches the spring *d*, the current flows through the wire from *A* to *B* and *C;* when it touches the spring *e*, the current flows first through the earth from *n* to *o*, and then through the wire from *C* to *A*. The permanent magnets connected with the pendulums *B* and *C* do not appear in the figure.

321. *The Electric Telegraph.* — *An instrument for sending signals between distant stations* is called a *telegraph.* The word means *writing at a distance.*

Four things are essential in every electric telegraph: (1) a battery for generating electricity; (2) wires to conduct the electricity; (3) an instrument for sending the message; and (4) an instrument for receiving the message.

The battery used is, in almost all cases, a voltaic battery. The sending instrument is merely a *key* for opening and closing the circuit, or for changing the direction of the current. The receiving instrument, in the *needle* telegraph, is a magnetic needle, which by its movements indicates the message sent. In *Bain's chemical* telegraph, an iron point makes blue marks on paper by the action of the current upon a compound (prussiate of potash) with which the paper has been moistened.

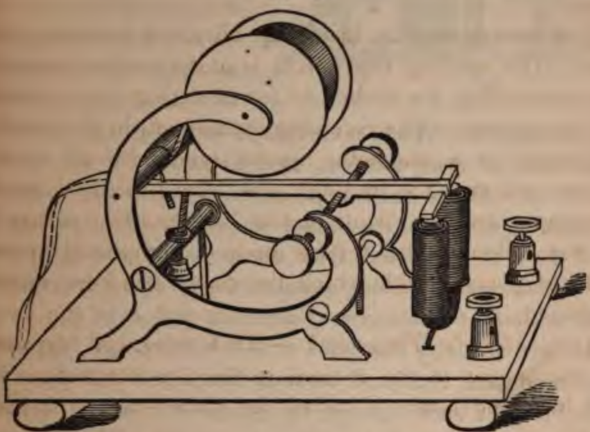
322. *Morse's Telegraph.* — This telegraph depends on the power of the current to develop magnetism in soft iron, and hence is called the *electro-magnetic* telegraph.

The essential parts of *the receiving instrument* are shown in Figure 185. One of the screw-cups at the right is connected with the wire from the distant station, and the other with the earth. The current traverses the coils of the electro-magnet, and draws down the keeper and the arm of the lever to which it is attached. The other end of the lever is raised, pressing a steel point, or *style*, against a strip of paper, which is unrolled from the bobbin above, and moved steadily along by clockwork not represented in the figure. When the current from the distant station is broken, the shorter arm of the lever is released by the electro-magnet, the longer arm falls back by its weight, and the style ceases to press

against the paper. If the style is raised for a moment only, a *dot* is made; if for a longer time, a *dash*. The *alphabet* used is made up by *the combination of dots and dashes*.

323. *The Earth may serve as a Telegraphic Wire.* —One wire is sufficient to connect two telegraph sta-

Fig. 185.

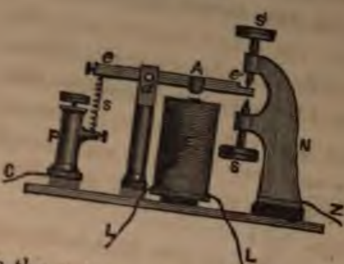


tions, if its terminations be formed by two large plates buried so deep that the earth about them never gets dry. The earth serves the purpose, not only of a second wire, but of one *so thick that its resistance is next to nothing* (316).

324. *The Relay.* — On long circuits there is a great loss of electricity by leakage on the way, so that a current strong at starting becomes very weak before it reaches the station to which it is sent. On such circuits it is usual to work the receiving instrument by a local current, and to include in the line circuit a very delicate instrument, called the *relay*, *which has only to make or break the local circuit*. The electro-magnet *E*, of the

relay (Figure 186) is included in the line circuit, ins[tead] of the electro-mag[net] of the receiving instru-ment. The coil is lon[g] and of very fine wi[re], and a very faint cur-rent is sufficient to de-velop magnetism in the core. The keeper, A, of the relay is attached to a lever, $e e'$, turning on the axis a. When a current is sent through the coil, the lever is drawn down, and the end e' rests on the screw S. When there is no current, the spring s brings e' back against the insulated screw S'. The pillars N and P are connected with the poles of the local bat-tery. The metal spring s places the lever $e e'$ in connec-tion with P. The screw S and the end e' of the lever, then, are virtually the poles of this battery. When these are in contact, the local current flows, and it stops when e' is brought back against the screw S'. The receiving instrument is included in the local circuit. When a cur-rent comes from the sending station, the keeper A is attracted, e' falls on S, the local circuit is closed, and the receiving instrument begins to print. When the current ceases, e' returns to S', and the style of the receiving in-strument is withdrawn from the paper. By this means, *a current too weak to work the receiving instrument can complete the local circuit and print legibly.*

Fig. 186.



325. *The Telegraphic Fire-Alarm.*—The electric telegraph is now extensively used for indicating the locality of fires in cities. In various parts of the city are small iron boxes called *signal-boxes*. They are all numbered, and connected with a central station by means of wires. By turning a crank which is found inside the

signal-box, the circuit is opened and closed in such a way as to telegraph to the central station the number of the box. When, therefore, a fire occurs in the neighborhood of any box, the box is opened, the crank turned, and *the number of the box telegraphed to the central station.* This station is also connected by wire circuits with bells in different parts of the city, and the operator, by means of the electric force, *rings on these bells the number of the box*, so that the firemen know at once the neighborhood to which they must go.

If the number of the box is ten or less, it is indicated by a corresponding number of strokes on the bell. If above ten, the digits of the number are indicated by striking the numbers corresponding to them with a short pause between. Thus to strike the number 25, two blows would be given, and then after a pause five more. Numbers containing ciphers and those made up of figures repeated, as 22, 33, etc., are not used for the signal-boxes.

SUMMARY.

The wire through which a current flows is magnetic.

This magnetism appears much stronger when the wire is bent into a coil, or helix.

When a piece of soft iron is placed inside a coil and a current sent through the wire, it becomes magnetic. A magnet made in this way is called an *electro-magnet*, and is much stronger than an ordinary magnet.

If the core of an electro-magnet is of soft iron, the magnetism can be destroyed by breaking the current, and the poles can be reversed by changing the direction of the current. If the core is of steel, it retains its magnetism permanently. (317, 318.)

Page's rotating apparatus illustrates one of the ways

in which the electric force may be made to do mechanical work. (319.)

The electric force has been used for regulating the motion of clocks. (320.)

Four things are essential in an electric telegraph; a battery, a conducting wire, a sending instrument, and a receiving instrument. (321.)

Morse's telegraph depends on the power of the current to develop magnetism. (322.)

The main battery is made to work a relay magnet, and a local battery to work the receiving instrument. By means of the relay magnet the operator can open and close the circuit of the local battery at a distance. (324.)

The electric fire-alarm is another form of the electro-magnetic telegraph. (325.)

ELECTROLYSIS.

326. *A Compound may be decomposed by the Current.* — A compound substance, as water, may be *decomposed*, or separated into its elements, by the electric current. This *decomposition by electricity* is called *electrolysis.* The literal meaning of the word is *loosening by electricity.* The *substance decomposed* is called the *electrolyte.* The *metallic conductors through which the current passes into and out of the electrolyte* are called *electrodes* (*roads of electricity*). That through which the electricity *passes in* is termed the *anode* (*road up*); and that through which it *passes out*, the *cathode* (*road down*). The electrolyte is always separated into two parts, *one of which appears at the anode* and *the other at the cathode.*

Water is a compound of two gases, *oxygen* and *hydrogen*, into which it can be separated by electrolysis. The

en appears at the anode, and the hydrogen at the de.

very compound liquid which is a conductor of electy may be decomposed by the current. Solid comds are not thus decomposed.

7. *The Electrolysis of Blue Vitriol.* — If two elecs of platinum be put into a solution of blue vitriol ure 187), bubbles of gas rise from the anode. This s found to be *oxygen*, which is one of the elements e blue vitriol. On removing the cathode the solution, it is found to be coated *copper*, which is another element in the vitriol. If one of the electrodes be of ium and the other of copper, and the ium be made the anode, the same results btained. If, however, the copper be the anode, the cathode is still coated copper, but no gas escapes from the anode. In this the anode is gradually dissolved in the liquid, and ferred to the cathode.

Fig. 187.

hen any compound containing a metal is decom-d by electricity, the metal always appears at the de; and *if the anode be of the same metal, it is ually transferred to the cathode.*

8. *Electrotyping.* — When the solution of blue vits decomposed slowly, the copper is deposited on the de in a tenacious mass, which, when stripped off, nts a perfect reverse image of the face of the cath-If this reverse image be now made the cathode, and er sheet of copper be deposited upon it, *an exact of the original electrode is obtained.* Any con-ig substance may be made a cathode by simply con-ig it with the negative pole of the battery. Hence medals, and engraved plates may be copied with t accuracy, and with but slight trouble and expense.

This process of *copying by means of electri*[city is] called *electrotyping*.

The face of a medal may be copied by making i[t the] cathode and depositing a sheet of copper upon it, [and] then depositing another sheet of copper upon this s[heet] after it has been separated from the medal. In prac[tice,] however, a mould of the thing to be copied is first t[aken] in some soft substance, such as plaster, gutta-perch[a, or] wax, and this mould is made the cathode. If the m[ould] is made of non-conducting material, as is usually the c[ase,] its surface must be covered with some conducting s[ub]stance, as powdered graphite.

One of the chief uses of electrotyping is *in copy*[*ing*] *printer's type* after it has been set up, and *in c*[*opy*]*ing wood engravings*. This book is printed from s[uch] copies, or *electrotype plates*. An impression is t[aken] of the type or the engraving in wax, which is t[hen] brushed over with powdered graphite, and made t[he] cathode; the electrolyte is blue vitriol, and the ano[de is] a piece of copper.

329. *Electro-plating*.—This is *the art of coati*[*ng*] *the baser metals with silver by the electric curre*[*nt*]. Articles to be electro-plated are generally made of bras[s,] bronze, copper, or nickel silver, this last being the be[st] material.

The bath is a large trough of earthen-ware or othe[r] non-conducting substance. It contains a weak solutio[n] of argentic cyanide (cyanide of silver) and potassi[c] cyanide (cyanide of potassium). A plate of silver form[s] the anode; and the articles to be plated, hung by wir[es] to a metal rod lying across the trough, constitute th[e] cathode. When the former is connected with the positi[ve] pole of a battery, and the latter with the negative pol[e,] the silver of the cyanide begins to deposit itself on th[e] suspended articles; while the silver anode is dissolve[d]

(327), furnishing a fresh supply of cyanide. The thickness of the plating depends on the length of time the articles are immersed.

330. *Electro-gilding.* — This process is essentially the same as electro-plating, except that the articles are coated with gold instead of silver. The electrolyte is some compound of gold, and the anode is a lump of gold.

331. *Electro-metallurgy.* — The *art of depositing, by electro-chemical action, a metal on any surface prepared to receive it*, is called *electro-metallurgy*. There are two kinds of electro-metallurgy, one of which is illustrated by electrotyping, and the other by electro-plating. The former includes all those cases in which the coating of metal merely *adheres* to the surface on which it is deposited, and is afterwards stripped off; and the latter, all cases in which the two metals *combine* with each other, and the coating remains permanently fixed. Gold, platinum, silver, copper, zinc, tin, lead, cobalt, and nickel can be deposited by electrolysis.

SUMMARY.

When any compound liquid which is a conductor of electricity forms a part of the circuit, it is decomposed. This decomposition by electricity is called *electrolysis*.

When the electrolyte contains a metal, this always appears at the cathode; and if the anode is of the same metal, it is gradually dissolved and deposited on the cathode. Advantage is taken of this fact in electrotyping, electro-plating, and electro-gilding. (326–330.)

In electrotyping, the metal deposited on the cathode merely adheres to it, and is afterwards removed; in electro-plating and electro-gilding, it permanently combines with the metal on which it is deposited. (331.)

POWER OF THE CURRENT TO DEVELOP HEAT AND LIGHT.

332. *Heat is developed by the Current.*—When a current passes through fine wire, an intense heat is produced, sufficient in some cases to bring it to a white heat, and even to fuse platinum wire. *If the wire be kept the same, or of the same resistance, the heat is in proportion to the square of the strength of the current.* Thus, if a current of a certain strength raise the temperature 1° in a minute, a current of twice the strength will raise it 4° in a minute.

Again, if the strength of the current be kept the same, and *wires of different resistance* be tried, *the heat developed is in proportion to the resistance of the wire.* Thus, if with a certain wire the temperature be raised 1° per minute, it will be raised 2° per minute with a wire of double the resistance.

Hence *the heat developed in a conducting wire by an electric current is proportional to the squares of the strengths of the current, and to the resistance offered by the wire.*

The power of the current to ignite fine wires of comparatively bad conductors, such as steel and platinum, is used to explode gunpowder at a distance, in blasting and mining. The current is transmitted to the point where the explosion is to take place by good conducting wires, the ends of which are connected in the gunpowder by fine steel wire. When the current is sent through the wires, the fine steel wire burns up and explodes the gunpowder.

333. *The Electric Light.— When the poles of a powerful battery are made to touch, and then are separated a little, the current forces its way through*

he intervening air, producing intense light and heat. The heat is sufficient to melt the most refractory metals, nd therefore some very infusible conductor must be used or the poles. The best, both for conducting power and lurability, is the coke carbon formed in the distillation of oal-gas.

When points made of this carbon are used as the poles, and are separated a little, while a strong current s passing through them, a light appears between them ivalling that of the sun in purity and splendor. This ight arises chiefly from the intense whiteness of the tips f the carbon points, and partially from an arch of flame xtending from one to the other.

The heat of this arch of flame, or *voltaic arc*, as it is alled, is *the most intense that can be produced.* Platiium melts in it like wax in the flame of a candle. Quartz, the sapphire, magnesia, lime, and even the liamond, are readily fused by it.

SUMMARY.

When the current passes through a conductor, heat is eveloped. The heat is proportional to the square of the trength of the current, and to the resistance offered by he conductor.

By introducing a poor conductor into any part of the ircuit, heat may be developed at that point. Advantage s taken of this fact in exploding gunpowder at a disance, and in producing the electric light. (332, 333.)

MAGNETO-ELECTRICITY.

334. *An Electric Current may be induced by a Magnet.*—Attach the lifting-coil to the galvanometer, lace the rod within the coil, and bring it quickly in

contact with the pole of an excited electro-magnet. Magnetism is developed in the rod, and the galvanometer shows a current in the wire of the coil. The needle soon returns to its former position. Now quickly detach the rod and coil from the magnet. The rod loses its magnetism, and the galvanometer shows a current in the coil, but its direction is the opposite of that of the former current.

Electricity thus *originated by a magnet* is said to be *induced* by it, and is called *magneto-electricity.*

335. *Magneto-Electric Machines.* — An *instrument for developing magneto-electricity* is called a *magneto-electric machine.* In ordinary machines of this kind, the electricity is induced by an electro-magnet, whose magnetism is alternately developed and destroyed by means either of a permanent magnet or of an electric current.

336. *Induction Coils.* — When the magnetism is developed and destroyed by means of a current, the soft iron must be placed inside a coil *through which the current is sent.* This is called the *primary coil,* and must be placed inside another coil, called the *secondary coil,* which serves as *a conductor of the induced electricity.* Such a magneto-electric machine is called an *induction coil.* In the one shown in Figure 188, the primary coil is of coarse wire wound with wool, and is attached to the wooden base of the instrument. The secondary coil is of finer silk-wound wire, much longer than the primary

Fig. 188.

wire. Within the primary coil is a bundle of iron wires, which are sufficiently insulated by the rust that gathers on them. The developing of magnetism in these wires is the chief aim of the primary coil, and, as this requires a *strong* current, *coarse wire* is used in that coil. In the secondary coil, the aim is to increase the *tension* of the induced current, and *fine wire* is used, so that as many turns as possible may be brought within the influence of the primary coil and its core; for it is found that *the tension of the induced current is proportional to the strength of the primary current, and to the square of the resistance in the secondary coil.*

In order to obtain the greatest effect from the secondary coil, *it is necessary to have some means of rapidly completing and breaking the primary current.* This is done either by means of the rasp seen behind the coils, or by the self-acting *rheotome* at the left hand.

337. *The Inductorium, or Ruhmkorff's Induction Coil.* — The essential parts of this apparatus, like those of the one just described, are *a primary coil, with its core of iron wire, and a secondary coil outside the primary and insulated from it.* The primary coil is connected with a galvanic battery, and a rheotome is used to interrupt the current, as already explained.

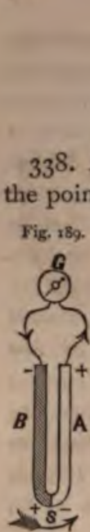
SUMMARY.

Electricity can be developed by magnetism, and is then called *magneto-electricity.* In all ordinary magneto-electric machines the electricity is induced by an electro-magnet, which is excited either by means of a permanent magnet, or of the electric current. In the latter case, the machine is usually called an ied rod of glass (334–337.) of silk or flannel,

THERMO-ELECTRICITY.

338. *Electricity may be developed by Heat.* — When the point of junction of any *two* metals is heated, a current is always produced. When a bar of antimony, *A*, is soldered to a bar of bismuth, *B* (see Figure 189), and their free ends are connected with a galvanometer, *G*, a current passes from the bismuth to the antimony when the junction is heated. When *S* is cooled by applying ice, or otherwise, a current in the opposite direction is produced. Such a combination of metals is called a *thermo-electric pair*. Electricity thus developed is called *thermo-electricity* (*heat* electricity).

Fig. 189.



Farmer's alloy (of zinc and antimony) forms a much more powerful pair with bismuth than antimony does.

339. *The Thermopile.* — One bismuth-antimony pair has very little power. To obtain a stronger current, several pairs are united, as shown in Figure 190. The heat in this case must be applied only to one row of soldered faces. The strength of the current depends on the difference of temperature of the two sides; and to increase it to the utmost, one series must be kept in ice or in a freezing-mixture, whilst the other is exposed to an intense heat. As in the galvanic battery, the electric force is proportionate to the number of pairs.

Fig. 190.

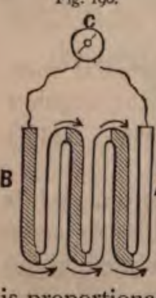
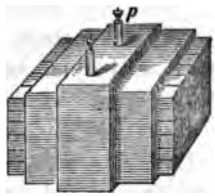


Figure 191 represents a common form of thermo-elec-
thermopile. It consists of thirty pairs,
of finer silk-woFigure 190. The binding-screws are

connected with the bars at the ends of the series. The bars are separated by a non-conducting substance, as gypsum, and the frame is made of non-conducting material.

Fig. 191.



The thermopile, in connection with a sensitive galvanometer, forms *the most delicate of differential thermometers* (291). So long as the opposite faces are exposed to the same temperature, no current is produced; but if the temperature of one side becomes higher than that of the other, a current is at once indicated. If the hand, for instance, be brought near one side, the needle shows a current; or if a piece of ice be held near, a current is also shown, but moving in the opposite direction.

SUMMARY.

Heat has power to develop electricity in a combination of different metals. Electricity thus generated is called *thermo-electricity*. (338.)

The thermopile is a very sensitive differential thermometer, since a current is developed by the slightest difference of temperature between the two faces. (339.)

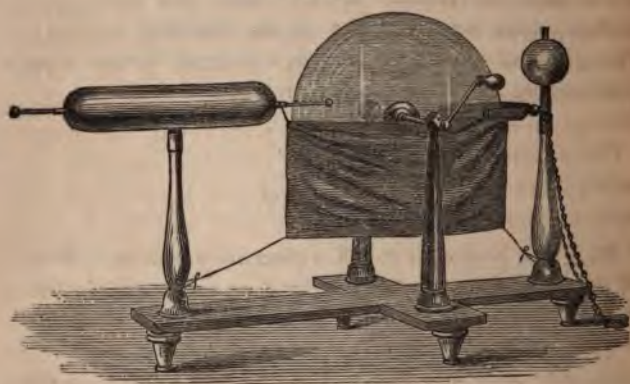
FRICTIONAL ELECTRICITY.

340. *Electricity may be developed by Friction.*—When a cat's back is stroked on a cold, dry day, in a darkened room, sparks are obtained which indicate the development of electricity. If a well-dried rod of glass or gutta-percha be rubbed with a piece of silk or flannel,

similar sparks appear. Electricity thus *developed by friction* is called *frictional electricity*. When any two dissimilar bodies are rubbed together, electricity is developed; but *when the substances are conductors, the electricity passes off silently* through the hands and body. In order to detect it, the substances rubbed together must be held by *insulating* handles; that is, *non-conducting* handles.

341. *The Electrical Machine.*—An *apparatus for generating frictional electricity* is called an *electrical machine*. The one shown in Figure 192 consists of a

Fig. 192.



thick plate of glass turned by a crank. At one end there is a glass standard surmounted by a brass ball. From this standard project two brass strips in the form of a clamp, which hold the *rubbers* against the glass plate. These rubbers are pieces of wash-leather or woollen cloth, covered with an *amalgam* of mercury, lead, and tin. At the opposite end, on a glass support, is a long cylinder of br[illegible]ss with rounded ends, called the *prime* or *positive* con[illegible]or. The brass ball connected with the

rubber is the *negative* conductor. The plate and conductors of the machine must be well insulated.

342. *Quantity and Intensity of Frictional Electricity.* — With a medium-sized machine of this kind, sparks are readily obtained two inches long by bringing a conducting substance near the ball of the prime conductor. Very large machines will give a spark two feet in length. Frictional electricity, then, must have great intensity, in order to traverse so great a distance of a non-conducting substance like the air. Its quantity, on the other hand, is next to nothing. This is shown by connecting the positive conductor with one end of the wire of a moderately delicate galvanometer, and the negative conductor with the other end, and working the machine. The needle will be turned aside scarcely at all. *The great tension and the small quantity* of frictional electricity place it in striking contrast with voltaic electricity.

The positive conductor of an electrical machine answers to the positive pole of a galvanic battery, and the negative conductor to the negative pole, and the friction on the plate to the chemical action in the cells. *With the galvanic battery an enormous quantity of electricity is obtained of slight tension; with the electrical machine, a small quantity, of enormous tension.*

343. *The Electroscope.* — If a pith ball hung by a silk thread from a glass rod be brought near the ball of a prime conductor, it is at first attracted and then repelled. This *power of attracting light bodies* is a marked feature of frictional electricity. *It furnishes the most ready means of detecting the presence of this electricity*, as the needle furnishes the most ready means of detecting voltaic electricity.

Fig. 193.

An instrument for the detection of frictional electricity is called an *electroscope*.

The *pith-ball electroscope* (Figure 193) consists of a brass conducting-rod supporting a graduated semicircle, in the centre of which is a movable index made of very light wood, with a pith ball at the end. When it is attached to the prime conductor of the machine, the pith ball is repelled as soon as the plate is turned.

Fig. 194.

The *gold-leaf electroscope* (Figure 194) is more sensitive. It consists of a hollow glass ball, through the cap of which passes a brass rod having a brass ball at its upper end and two narrow strips of gold-leaf hung from its lower end. If the brass ball be brought near a body charged with electricity, the strips of gold-leaf repel each other, as in the figure.

344. *The Electrical Forces on the Positive and Negative Conductors act in Opposite Directions.*—Insulate both conductors, and charge them with electricity. Bring a pith ball suspended by a silk thread in contact with the positive conductor, and it will be repelled. Take it now to the negative conductor, and it will be strongly attracted. A ball which is repelled by the force on one conductor is attracted by the force on the other; in other words, the two forces act in opposite directions.

345. *Both Electrical Forces are always developed together.*—It is impossible to develop one of these forces without at the same time developing both. One force always appears upon one of the substances rubbed together, and the other force always appears upon the other. *The force that acts in the same way as that upon the prime conductor* of the machine is called *positive electricity*, and *the opposite force* is called *negative electricity*. In order that both the forces should be detected, both the substances rubbed together must be insulated.

346. *Induction.*—If an insulated copper ball be connected with the prime conductor when charged, and a small insulated conductor be placed near it (Figure 195), opposite electrical forces will be developed upon the ends of the insulated conductor. On the end next the ball, negative force will be found; on the end farthest from the ball, positive force. This *action of a charged body upon a body near it* is called *induction.*

Fig. 195.

When the two opposite forces exist on a conductor, it is said to be *polarized; when only one force exists on it*, to be *charged;* and *when no force exists on it*, to be *neutral. When a force which has been developed on an insulated conductor passes off*, it is said to be *discharged.*

347. *The Charge on a Solid Insulated Conductor is always on the Surface.*—To an insulated copper ball are carefully fitted two hemispherical metallic caps provided with insulating handles. The caps are placed upon the ball, and the whole apparatus is charged. The caps are then removed, and *are found to be charged*, while *not the slightest trace of a charge is found on the ball.*

When a *spherical* conductor is charged and placed in the centre of a room, *the charge is distributed uniformly over its surface;* if the conductor be *oblong*, the charge *accumulates at the ends.*

348. *The Leyden Jar.*—The Leyden jar is a wide-mouthed jar of thin glass, coated with tinfoil on both sides to within an inch or two of the top, and closed with a stopper of cork or dry wood, through which a brass rod passes, terminating outside in a ball, and connected inside with the tinfoil coating. The jar is charged by connecting its outer coating with one conductor of an

electrical machine in action, and the inner coating with the other. Each surface of the glass becomes charged with the same electric force as the conductor with which it is connected. The coatings serve merely to conduct the electricity over the surface of the glass in charging and discharging the jar.

The jar may be discharged by means of the *discharger*, which consists of two bent brass arms connected by a movable joint and having brass balls at their ends. It is fastened at the joint to a glass handle. To discharge the jar, hold the discharger by the glass handle, and bring one ball in contact with the outer coating and the other ball near the knob connected with the inner coating.

349. *The Leyden Battery.*—The amount of charge which a Leyden jar can receive, other things being equal, evidently increases with the size of the coatings. The area of the coatings can be most conveniently increased *by connecting together several jars* as a *Leyden battery*. Like the cells of the voltaic battery (309), the jars can be connected in two ways: (1) the outer coating of one may be connected with the inner coating of the next, and so on throughout the series; or (2) the outer coatings may all be connected together, and also the inner coatings. In the first case, the battery is discharged by bringing the inner coating of the first jar in contact with the outer coating of the last; in the second case, by bringing the connected outer coatings in contact with the connected inner coatings. Like the voltaic battery, when the Leyden battery is arranged in the *first* way, it gives electricity *of the greatest intensity;* and, in the *second* way, electricity *of the greatest quantity*.

350. *The Effect of Points on a Conductor.*—It is impossible to charge a conductor when a sharp point projects from it, or is held near it. *The point conveys away the electric force silently.* If the hand be held in

front of the point when the electricity is developed, a current of air is distinctly felt setting off from the point. If a lighted taper be held near the point, the flame is blown away from it. *The electric force is carried off by the molecules of air which form the current*, and hence it is called *convective discharge.* Since in a darkened room *a star of light is seen upon a point held near an electrical machine* in action, this silent discharge is also called *glow discharge.*

The charge rises so high at the point that the molecules of air just about it are strongly polarized. They then act like little pith balls, being first drawn to the point and then driven from it, thus producing the current of air.

351. *The Electric Wheel.*—As each molecule is repelled from the point, *it also repels the point itself, which, if free to move, will be set in motion.* This is shown by the *electric wheel* (Figure 196), which consists of a number of points all bent round in the same direction. The wheel is poised so as to turn easily, and when connected with the prime conductor of the machine in action, it rotates rapidly, each point moving backwards.

Fig. 196.

SUMMARY.

When unlike substances are rubbed together, *frictional electricity* is developed. (340.)

Frictional electricity has slight quantity, but enormous tension; while voltaic electricity has slight tension, but enormous quantity. (342.)

Two opposite electrical forces are developed on the two conductors of the electrical machine; and one cannot be developed without the other. (344, 345.)

A body is *polarized* when it has opposite electric-

forces developed on opposite parts; it is *charged* when it has only one electrical force upon it.

A body charged with either electrical force polarizes an insulated conductor near it, *inducing* upon the face nearest itself the opposite electrical force. (346.)

Each surface of a Leyden jar becomes charged with the electricity of the conductor with which it is connected, the tinfoil serving to distribute the electricity over the surface. The jar is discharged by connecting the two coatings by a conductor. (348.)

The action of points on charged bodies is to convey the charge off silently by *convective discharge*. (350.)

NOTE.—A brief account of *Atmospheric Electricity* will be found in the *Appendix*, pages 256–261.

APPENDIX.

PHYSICS OF THE ATMOSPHERE.

TEMPERATURE OF THE ATMOSPHERE.

1. *Composition of the Atmosphere.*—The atmosphere is a gaseous ocean surrounding the earth to the depth of about fifty miles. It is mainly a mixture of two gases, *nitrogen* and *oxygen*, in the proportion of 79.1 parts of the former to 20.9 of the latter. It contains also a little *carbonic acid* and a variable amount of *watery vapor*.

2. *The Air receives its Heat directly or indirectly from the Sun.*—A part of the solar rays are *absorbed* in passing through the atmosphere. It thus becomes warmed *directly* by *solar radiation*. A part of the rays fall upon the surface of the earth, which absorbs them, and thus becomes heated. This heat is then radiated back again, and is absorbed by the air, which thus becomes heated by *terrestrial radiation*.

Owing to the greater specific heat of water, the sea becomes less heated during the day than the land does. Again, it is a poorer radiator than the land. Hence, *the terrestrial radiation from the land is much greater than from the sea.*

The watery vapor in the air allows the rays of the sun to pass readily through it on their way to the earth, but it will not allow them to pass back again when they are radiated from the earth as obscure heat. *The sunbeams are thus caught in a trap* from which they cannot escape.

This is the main reason why it is warmer at the base of a mountain than at its top, where the solar radiations are more powerful. In the upper regions of the atmosphere, there is less watery vapor to absorb the terrestrial radiations.

3. *The Daily Variation of Temperature.* — The temperature is *greatest, not at noon, but two or three hours later;* and *least, not at midnight, but an hour or two before sunrise.* During the forenoon, the earth receives more heat than it radiates. In the afternoon it begins to receive less heat, but for two or three hours it still receives more than it radiates, so that it grows hotter and gives out more heat than at noon. During the night, it receives no heat from the sun, and gives out less and less till about an hour before sunrise, when the heat it receives from the returning sun again equals what it radiates.

4. *The Distribution of Temperature in the Atmosphere.* — The *highest* temperature of the earth is found to be *in an irregular belt lying within the tropics.* The warm belt is continually shifting its position, passing northward with the sun until midsummer, and then southward again until midwinter.

From the warm belt, *the temperature diminishes towards the poles.* In the *southern* hemisphere, which is nearly all *water*, it shades off *gradually and regularly;* in the *northern*, where there are large bodies of *land*, the changes are quite *irregular.* In the summer the atmosphere over the continents becomes much hotter than over the ocean, owing to the greater radiation from the land; while in the winter the air over the continents is much colder than over the ocean, since the land has cooled down faster than the sea.

The distribution of heat is also modified by the *oceanic currents* and the prevailing *winds.* The Gulf Stream and the southwesterly winds keep the temperature of western Europe much above that of the eastern coast of America in the same latitude. For a similar reason, the western coast of America is warmer than the eastern coast of Asia.

ATMOSPHERIC PRESSURE.

5. *The Daily Variation of Atmospheric Pressure.* — The barometer shows two *maxima* and two *minima* of atmospheric pressure during the day: the former occurring from nine to eleven, A.M., and from nine to eleven, P.M.; and the latter from three to

·, A.M., and from three to five, P.M. These variations are ch more marked in tropical regions than elsewhere.

5. *The Distribution of Atmospheric Pressure.* — In general, re is *an irregular belt of low pressure within the tropics, unded on each side by a broad belt of high pressure. North and ith of these are other belts of low pressure*, while *about each le there is probably a region of high pressure.* The belts south the equator are much more uniform and regular than those rth of the equator; as may be seen by reference to Map I. (at e end of the book) on which the blue lines represent pressures low thirty inches, and the red lines thirty inches and above.

In winter (as shown in Map II.), the north polar region of w pressure has two centres of least pressure; one in the orthern Atlantic near Iceland, and the other in the northern acific. At the same time, there is a broad belt of high pressure retching across Asia and North America, with a centre of reatest pressure on each continent.

In summer (as shown in Map III.), there are centres of high ressure in the middle of the northern Atlantic and Pacific; and broad band of low pressure stretching across North America nd Asia, with a centre of least pressure on each continent.

There are two things which tend to diminish the atmospheric ressure; *high temperature* and *great humidity.* High tempera- re causes the air to expand, rise, and flow away to colder gions. Great humidity diminishes the density of the air. umid air therefore rises, but in rising, it becomes cooled, and part of its moisture falls as rain. In this condensation, a large mount of heat is given out, which again raises the temperature f the air, and causes it to expand still more.

Now *in the tropics there is an excess of both heat and moisture.* he air therefore *rises and flows over towards the north and uth*, giving rise to the belt of low pressure bounded by belts of igh pressure.

Again, in the regions north and south of these belts of low ressure, the air is highly charged with moisture brought thither y the prevailing winds, and continually condensed in rain. ere also, then, the air rises and flows over towards the north

and south, producing a region of high pressure towards the poles and increasing the pressure in the belts towards the equator.

The irregularity in the belts of pressure in the northern hemisphere is *caused by the continents.* In the summer, both North America and Asia become excessively heated, while the adjacent seas are comparatively cool. Hence *the air pours over from the land to the sea*, giving rise to low pressure on the continents and high pressure on the oceans. The more completely the sea is shut in by the heated land, as in the northern Atlantic, the greater the atmospheric pressure upon it. It is also this excessive heat of the northern continents in summer which causes the great pressure upon the southern hemisphere at the same season. (See Map III.)

In winter, the conditions are reversed. The land becomes excessively cold, and the air over it dense and contracted. *The warmer air from the sea now pours over upon the land*, causing the high pressure in North America and Asia, and the low pressure in the northern Atlantic and Pacific. (See Map II.)

WINDS.

7. *Cause of Winds.* — Winds are *currents of air*, and are *directly caused by atmospheric pressure.* If two neighboring regions come to be of very unequal temperature, the lighter air of the warmer region will rise and flow over to the colder region, while the heavier air of the colder region will flow in below to supply its place. Thus we always have a surface wind blowing from a region of lower temperature and high pressure towards one of higher temperature and low pressure, and an upper wind blowing in the opposite direction. We have an illustration of this in the wind which always sets in from every direction towards a large fire. We have another in the *land* and *sea breezes.* On the sea-coast a breeze sets in from the sea in the morning. At first a mere breathing, it gradually rises to a stiff breeze in the heat of the day, and again sinks to a calm towards evening. Soon after, a breeze springs up from the land, and blows strongly

seaward during the night, dying away towards morning, when the sea-breeze begins once more. These breezes are especially marked in tropical regions, where the difference of temperature on land and sea is greatest.

8. *Trade-Winds.* — While the air above is flowing north and south from the tropical belt of low pressure, a surface wind will set in from the region of high pressure to supply its place. Were the earth at rest, these surface winds would blow directly from the north and south towards the equator. But *the earth is rotating from west to east*, and objects on the surface at the equator are carried round towards the east at the rate of about 17 miles a minute. But as we go away from the equator, this velocity diminishes, so that in latitude 60° it is only 8½ miles a minute, and at the poles it is nothing. The wind, then, blowing towards the equator, *is continually coming to places which have greater velocity eastward than itself, and therefore lags behind and appears to move westward.* This, *combined with its motion towards the equator*, makes the surface wind north of the equator a *north-east* wind, and the one south of the equator a *south-east* wind. These winds blow with great steadiness and constancy, and from the service they render to commerce are called *trade-winds.*

In mid-ocean in the Atlantic, the *north trades* prevail between latitudes 9° and 30°, and in the Pacific, between latitudes 9° and 26°; and the *south trades* in the Atlantic, between latitudes 4° north and 22° south, and in the Pacific between latitudes 4° north and 23½° south. These limits are, however, not stationary, but follow the sun, advancing northward from January to June, and retreating southward from July to December.

9. *Region of Calms.* —The region of calms is *a belt of about 4° or 5° in breadth, stretching across the Atlantic and the Pacific, generally parallel to the equator.* It is marked by a lower atmospheric pressure than is found to the north and to the south of it in the regions of the trade-winds. It is also characterized by the daily occurrence of heavy rains and severe thunder-storms. The position of the belt varies with the sun.

There are *two other regions or belts of calms at the limits of*

the north and south trades. Except in the Pacific Ocean, these belts are either broken up, so as to appear only in patches, or are completely obliterated by the disturbing influences arising from the unequal distribution of land and water. Of these smaller regions of calms, the most interesting is that marked out by the high pressures in the North Atlantic. This is the region of the *Sargasso Sea*, which is thus characterized not only by its still waters, but also by its still atmosphere. A similar region of calms exists in the South Atlantic. These calms are well known to sailors.

10. *Winds in Middle Latitudes.* — Surface winds will flow from the belts of high pressure, not only towards the equatorial belt of low pressure, but also *towards the belts of low pressure on the other side.* These currents are continually coming to places which have *less* velocity eastward than their own, and therefore appear to move *eastward.* This, combined with their motion from the equator, tends to make them *south-west* winds in northern latitudes and *north-west* winds in southern latitudes. These are the prevailing winds in these regions, but, owing to various disturbing causes, they are *much less uniform and constant than the trade-winds.* This is especially true of the northern region.

There will also be surface winds blowing *from the poles* towards these same belts of low pressure. Of course, *there will be upper currents in opposite directions to all these surface winds.*

11. *Winds of the Northern Atlantic.* — It is found that wherever there is a *centre* of low pressure, the winds blow towards it, not directly, but *spirally*, and somewhat to the *right* of it. We have an illustration of this in the winter winds of the northern Atlantic, when there is a centre of low pressure near Iceland. Along the North American coast the prevailing winds are from the N.W. At the more northern places the general direction is more northerly, while farther south it is more westerly. In the Atlantic, between Great Britain and America, the direction is nearly S.W.; this is also nearly the direction in France, Belgium, and the south of England. At Dublin, and in the south

of Scotland, it is about W.S.W.; at Copenhagen it is S.S.W.; at St. Petersburg, it is nearly S.; and at Hammerfest, near the North Cape in Norway, it is S.S.E. We thus see that *the whole atmosphere flows in towards and upon the region of low pressure round Iceland,—not directly towards the region of lowest pressure, but in a direction a little to the right of it.* We can now understand why it is that the prevailing winds in North America at this season are N.W., while in Greenland and in Great Britain a N.W. wind is scarcely known.

It is mainly to this low pressure which draws over Great Britain the S.W. winds from the warm waters of the Atlantic that this island owes its mild, open, and rainy winters. It is the same pressure which gives Russia and Central Europe their severe winters, since on account of it a slow, steady air-current from the cold regions of Northern Asia is drawn westward over those parts of Europe. Finally, the same low pressure draws over British America and the United States, by the N.W. wind, the cold, dry currents of the polar regions. In the State of Maine, the mean January temperature is about 23°, whilst on the coast of England, 10° farther north, it is as high as 40°.

12. *Monsoons.*—The term *monsoon*, derived from the Arabic word *mausim* (a set time or season of the year) has been long applied to the prevailing winds in the Indian Ocean, which blow from the S.W. from April to October, and from the N.E., or opposite direction, from October to April. During the summer, when the sun is north of the equator, the continent of Asia becomes heated to a much greater degree than the Indian Ocean, which in its turn is warmer than Australia and South Africa. Hence, as the heated air of Southern Asia expands and rises, and the pressure is thereby reduced nearly half an inch below the average, colder air from the S. flows in to take its place, and thus *a general movement of the atmosphere of the Indian Ocean sets in towards the N.*, giving a *southerly* direction to the wind. But as the wind comes from parts of the globe which revolve quicker to those which revolve more slowly, *it gets a westerly direction.* The combination of these two directions results in *the S.W. monsoon,* which accordingly pre-

vails there *in summer*. Since, during winter, when the sun is south of the equator, Asia is colder than the Indian Ocean, and the pressure is thereby increased nearly half an inch above the average, *a general movement of the atmosphere sets in towards the S. and W.* As this is *the same direction as the ordinary trade-wind*, the result during *winter* is not to change the direction of that wind, but only to *increase its velocity*.

Similar, though less strongly marked monsoons prevail off the coasts of Upper Guinea in Africa, and Mexico in America.

STORMS.

13. *Storms.*—Besides the general atmospheric disturbances already described, there are *local disturbances* of the same kind, called *storms*. When the air over any considerable tract becomes excessively heated and humid, it rises and overflows, producing a local centre of least pressure. *Surface winds set in towards this centre from all sides in a spiral direction*; as the humid air rises it becomes cooled, and its moisture is condensed as rain or snow. A large amount of heat is set free, which causes the air to expand still more. Sometimes these storms remain stationary, but they *generally move forward in an easterly direction*.

The storms of North America usually have their rise in the region east of the Rocky Mountains, travel eastward towards the coast, and cross the Atlantic. They are preceded by a high temperature and a moist air, and followed by a low temperature and a dry air. When the storm is approaching, the wind sets in from the east, and there is usually the heaviest fall of rain before the centre of the storm arrives. In this centre there is usually a calm, and often considerable clear sky. As the centre passes, the wind suddenly veers round to the west, and a short, heavy fall of rain follows; the temperature rapidly falls, and the barometer rapidly rises. When the centre of the storm passes to the north, the wind sets in from the south-east, and veers round by the south to the south-west. When the centre

f the storm passes to the south, the wind sets in from the orth-east, and veers round by the north to the north-west.

When a great storm begins near the Mississippi, the wind at t. Louis will be easterly, while farther east it will be westerly. his easterly wind travels eastward with the storm; that is, in direction *opposite* to that in which it blows. The westerly ind which follows the storm travels along with it; that is, in e *same* direction as that in which it blows.

The storms of America are usually *very long in a north and uth direction, and travel side foremost;* while *the storms of urope* are usually *circular or slightly oblong in the direction f their motion.* The latter are followed by less depression of mperature than those of America.

Tornadoes are *very violent storms*, usually of small dimenons. Here, as in other storms, the wind sets in spirally wards the region of least pressure, which is also the centre the storm.

14. *Whirlwinds.* — *Whirlwinds* are very different from the orms already described. They *seldom last longer than a*

Fig. 197.

inute, sometimes only a few seconds; their *breadth varies om twenty to a few hundred yards;* their *course seldom ex-*

ceeds 25 miles in length; and, while they last, *the wind are sudden and violent*. The directio of the whirlwind is not uniform, as in a storm, b the direction of the stronger of the two winds w to it. Thus, suppose a whirlwind be produced by of a north wind against a south wind: then, if th be the stronger and on the west, the whirl will be tion of the hands of a watch; but if the south stronger, the eddy will turn in the opposite direc

Whirlwinds are often originated *in the tropics* hot season, especially in flat, sandy deserts, which unequally heated by the sun, give rise to numerous columns of air. In their contact with each other, th ing currents give rise to eddies, thus producing which carry up with them clouds of dust. Of this

Fig. 198.

are the *dust-whirlwinds* of India, illustrated in Figures 197 198. The large arrows, in Figure 198, show the rotation of t

whole whirlwind round its axis, while the small arrows show the rotation of each column round its own axis. Figure 197 shows the general appearance of a dust-whirlwind as seen from a distance. A dust-storm is *caused by a number of whirlwind columns moving together over the earth.* The storm generally comes on without warning from any direction, and the barometer is said not to be perceptibly affected by it. A low bank of dark cloud is seen in the horizon, which rapidly increases, and, before the spectator is aware, the storm bursts upon him, wrapping every thing in midnight darkness. An enormous quantity of dust is whirled aloft, which is sometimes broken into distinct columns, each whirling on its axis. Violent gusts or squalls succeed each other at intervals, which gradually become weaker; and, at the close of the storm, a fall of rain generally takes place. The air is often highly electrical, arising probably from the friction of the dust-laden currents against each other. The *Simoom* may be regarded as in part a whirlwind, or a succession of whirlwinds of this description. Sir S. W. Baker thus graphically describes the behavior of the dust-whirlwinds which occur in Nubia in April, May, and June: "I have frequently seen many such columns at the same time in the boundless desert, all travelling or waltzing in various directions, at the fitful choice of each whirlwind; this vagrancy of character is an undoubted proof to the Arab mind of their independent and diabolical character."

Extensive fires, such as the burning of the prairies in America, and *volcanic eruptions*, also cause whirlwinds by the upward current produced by the heated air; and these, as well as the other whirlwinds already mentioned, are occasionally accompanied with rain and electrical displays.

15. *Waterspouts.* — Waterspouts are *whirlwinds occurring over the sea or over sheets of fresh water.* When fully formed, they appear as tall pillars stretching from the sea upward to the clouds, and whirling round their axes, like the dust-whirlwinds. The sea is tossed into violent agitation round their bases as they career onward. The danger arising from them consists in the enormous velocity of the wind, and the sudden changes

in its direction. It is a popular fallacy that the water of the sea is sucked up by them, it being only the spray from the broken waves that is carried up by the whirling vortex. This is proved by the fact that the water poured down on the decks of vessels from waterspouts is either fresh or only slightly brackish.

THE MOISTURE OF THE ATMOSPHERE.

16. *The Two Atmospheres of Air and Vapor.*—The gaseous envelope of the earth may be considered as made up of two distinct atmospheres,—one of dry air, and one of vapor. The dry air is always a gas, and its quantity is constant from year to year; but the vapor of water does not always remain in the gaseous state, and the quantity in the atmosphere varies every instant.

17. *Evaporation.*—Vapor is continually passing into the air from the surface of water and moist bodies at all temperatures by the silent process of *evaporation*. Evaporation also takes place from the surface of snow and ice. The atmosphere can contain only a certain amount of vapor, according to the temperature; hence, when it is *saturated* with moisture, evaporation *ceases*. Conversely, evaporation will be ***greatest when the air is perfectly free from vapor.*** Since atmospheric currents remove the saturated air and substitute dry air, evaporation is ***much more rapid in windy than in calm weather.***

18. *Loss of Heat by Evaporation.*—We have learned that when a liquid passes into the gaseous form, a large quantity of heat becomes *latent;* and that this heat becomes ***sensible*** again when the vapor returns to the liquid state. ***The ocean loses more heat from evaporation than the land,*** because the quantity evaporated from its surface is much greater. Again, ***since more rain falls on land than on sea,*** especially in hilly and mountainous countries, ***the temperature of the air over the land will be still further raised*** by the heat thus given out. This is one of the reasons why the mean temperature of the northern hemisphere is higher than that of the southern.

It is for this reason that *the sensible temperature depends on the humidity of the air.* Dry air promotes evaporation from the surface of the body, and seems cold; while moist air impedes this evaporation, and seems warm. When the air is both hot and moist, as in the dog-days, it is peculiarly oppressive. It is because the winds promote evaporation that the air seems cooler on a windy day than on a still one, though the temperature may be the same.

19. *Dew.*—After the sun has set, the earth is continually radiating heat into space, and is receiving little or none in return. As it cools down, *it cools the layer of air nearest to it, and causes it to deposit its moisture* in the form of *dew.* In the same way, in hot weather, moisture collects on the outside of a pitcher of ice-water. The cold pitcher cools the air nearest it, and compels it to give up a part of its moisture.

Every one has noticed that dew collects on some substances more readily than on others. This is because they are *better radiators,* and therefore cool sooner.

Dew does not collect on a cloudy night, or under a roof or shed, because *the heat is sent back* by the clouds and the roof *as fast as it is radiated from the earth.*

There is no dew on a very windy night, because the layer of air near the earth is continually changing, and does not become cool enough to give up its moisture.

20. *Dew-point.*—The ascertaining of the dew-point is of great practical importance, particularly to horticulturists, since *it shows the point near which the temperature during the night will cease to fall.* For when the air has been cooled down by radiation to this point, dew is deposited, heat is given out, and the temperature of the air rises. But as the cooling by radiation proceeds, the air again falls to, or slightly under, the dew-point; dew is now again deposited, heat liberated, and the temperature raised. Thus the temperature of the air in contact with plants and other radiating surfaces may be considered as gently oscillating about the dew-point. For if it rises higher, the loss of heat by radiation soon lowers it; and if it falls lower by ever so little, the heat liberated by the formation of dew soon raises it.

The dew-point, then, determines the lowest temperature of the night; and if this point be found by means of the hygrodeik, the approach of low temperature, or of frost, may be foreseen and provided against.

MISTS, FOGS, AND CLOUDS.

21. *Mists and Fogs.*—Mists and fogs are ***visible vapors floating in the air near the surface of the earth.*** They are produced in various ways,—by the mixing of cold air with air that is warm and moist, or by whatever tends to lower the temperature of the air below the dew-point.

During a calm, clear night, when the air over a level country has been cooled by radiation, and dew begins to be deposited, the portion of the air in contact with the ground is lowered to the dew-point, and thus becomes colder than the air above it. Since there is nothing to disturb the equilibrium and give rise to currents of air, and no cause in operation which can reduce the temperature much below the point of saturation, the air within a few feet of the surface remains free from mist or fog. But if the ground slopes, the cold air, being heavier, will flow down and fill the lower grounds; and since it is colder than the saturated air which it meets with in its course, it will reduce its temperature below the point of saturation, and thus produce a *fog*.

When an *oceanic current* meets a shoal in its course, the cold water of the lower depths is brought to the surface, and in all cases where its temperature is lower than the dew-point of the air, fogs are formed over the shoal. For a similar reason *icebergs* are frequently enveloped in fogs. In like manner, mist is sometimes seen to rise from ***rivers whose temperature is lower than that of the air.*** Thus the waters of the Swiss rivers which issue from the cold glaciers cool the air in contact with them below the point of saturation, and produce mist. So, also, such rivers as the Mississippi, which ***flow directly into warmer latitudes,*** and are therefore colder than the air above them, are often covered with mist or fogs.

When rivers are considerably *warmer* than the air, the more rapid evaporation from the warm water pours more vapor into the atmosphere than it can hold, and the surplus is condensed into mist. Thus deep lakes, and rivers flowing out of them, are in winter generally much warmer than the air, and hence, when the air is cold and moist, they are covered with fogs.

The *densest* fogs occur *during the cold months in large towns built on rivers*, since the causes which produce fogs are then most active. The peculiar denseness of the London November fogs is caused by the warmth of the river-bed, and it is increased by the sources of artificial heat which London affords; and since the temperature is falling everywhere, and the air is very moist, its vapor is quickly and copiously condensed by the cold easterly winds of the season.

In all these cases, the fogs do not extend very widely nor rise very high. There are, however, other *fogs that spread over large districts*, like the fogs which often accompany the breaking up of frosts in winter. When the moist south-west wind has gained the ascendency, it is chilled by contact with the cold ground, and its abundant vapor condensed into mist.

Mountains are frequently covered with mist. As the warm air is driven up the slopes of the mountain by the wind, it becomes gradually colder, until at last its moisture is condensed. Mists often appear soonest on the parts of hills covered with *trees*, especially when the mist begins to form after mid-day, because then the temperature of the trees is lower than that of the grassy slopes. Occasionally the summit of a hill or an isolated peak is wrapped in mist, while elsewhere the air is clear; and though a breeze be blowing over the hill, still

> "Overhead
> The light cloud smoulders on the summer crag,"

apparently motionless and unchanged. This is easily explained. The temperature at the top is below the dew-point of the atmospheric current. Hence when the air rises to this region, its moisture is condensed into mist. This is borne forward over the hill and down the other side, acquiring heat as it descends

till it is again dissolved and disappears. Meanwhile its place is constantly supplied by fresh condensation, as the current rises to the summit. Thus, though the mist on the top of the hill *appears* motionless and unchanged, it *is continually undergoing renewal.*

22. *Clouds.* — Clouds are *visible vapors floating in the air at a considerable height;* thus differing from mists and fogs, which float *near the surface.* Both arise from the same causes.

During the warmest part of the day, when evaporation is greatest, warm, moist air-currents are constantly ascending from the earth. As they rise in succession, the moist air is pushed high up into the atmosphere, and loses heat by expansion until it can no longer retain its moisture. Hence condensation takes place, and a cloud is formed, which increases in bulk as long as the air continues to ascend. But as the day declines, and evaporation is checked, the ascending current ceases; and, the temperature falling from the earth's surface upwards, the lower stratum of air contracts. Consequently the whole mass of air begins to descend, and the clouds are then dissolved by the warmth they acquire in falling to lower levels. The whole of this process is frequently seen on a warm summer day. In the morning the sky is cloudless, or nearly so; as the heat becomes greater, clouds begin to form before noon, and gradually increase in numbers and size; but, as the heat diminishes, they contract their dimensions, and gather round the setting sun, lit up with the fiery splendors of his beams. In a short time they disappear, and the stars come out, shining in a cloudless sky.

The whole atmosphere, to a great height, is constantly traversed by many *aerial currents,* one above another, and flowing in different and frequently in opposite directions. Masses of air of different temperatures are thus frequently brought together; and since, when mingled, they cannot hold the same quantity of vapor that each could retain before they were united, the excess is condensed into cloud.

But again, when *a dry and heavy wind takes the place of a moist and light wind,* it generally edges itself beneath the moist wind and forces it, as with a wedge, into the upper regions of

he atmosphere. There its vapor is soon condensed, and dense lack clouds, often heavily charged with rain, are formed.

Currents of air driven up the sloping sides of hills and mountains by the winds often cause the formation of clouds (21).

23. *How Clouds are suspended in the Air.*—The cloud itself nay *appear* stationary or suspended (21), but *the particles of which it is composed are undergoing constant renewal.* The paricles are upheld by the force of the ascending current in which hey are formed; but when that current ceases to rise, or when hey become separated from it, they begin to fall through the ir by their own weight, till they melt away and are dissolved in he higher temperature into which they fall. Hence, *every cloud s either a forming cloud, or a dissolving cloud.* While it is conected with an *ascending* current, it *increases in size, is dense at he top, and well defined in outline;* but when the ascending current *ceases*, the cloud *diminishes in size and density.*

24. *Classification of Clouds.*—Clouds are divided into *seven kinds;* three being simple, the *cirrus*, the *cumulus*, and the *stratus;* and four intermediate or compound, the *cirro-cumulus*, he *cirro-stratus*, the *cumulo-stratus*, and the *cumulo-cirro-stratus* or *nimbus.*

These forms of clouds, with the exception of the *nimbus*, are epresented in the plate on page 249. The one marked by *one* bird is the *cirrus;* by *two* birds, the *cirro-cumulus;* by *three*, the cirro-stratus; by *four*, the *cumulus;* by *five*, the *cumulo-stratus;* by *six*, the *stratus.*

25. *Cirrus Cloud.*—The *cirrus* (or *curl*) cloud consists of *parallel, wavy, or diverging fibres* which may increase in any or in all directions. Of all clouds it has the *least density*, the *greatest elevation*, and the *greatest variety of figure.* It is the cloud first seen after serene weather, appearing as slender filanents stretching like white lines pencilled across the blue sky, and thence spreading in one or more directions, laterally, or upward, or downward. Sometimes the thin lines of cloud are arranged *parallel to each other*, the lines lying in the northern hemisphere from north to south, or from south-west to northeast; sometimes they *diverge from each other* in the form of the

tail of a horse; while at other times they *cross each other* in different ways like rich, delicate lace-work. It is probable that the fine particles of which this cloud is composed are minute *crystals of ice or snow-flakes*. The duration of the cirrus varies from a few minutes to many hours. It remains for a short time when formed in the lower parts of the atmosphere and near other clouds, and longest when it appears alone in the sky and at a great height.

25. *Cumulus.* — This name is applied to convex or conical *heaps* of clouds increasing upwards from a horizontal base. They are usually of *a very dense structure*; are *formed in the lower regions of the atmosphere*; and are *carried along in the current next the earth*. The cumulus has been well called the *cloud of the day*, being *caused by the ascending currents of warm air* which rise from the heated ground. Its beginning is the little cloud not bigger than a man's hand, which is the nucleus round which it increases. The lower surface remains roughly horizontal, while the upper rises into towering heaps, which may continue comparatively small, or swell into a size far exceeding that of mountains.

When these clouds are of moderate height and size, of a well-defined curved outline, and appear only during the heat of the day, they indicate a continuance of *fair weather*. But when they increase with great rapidity, sink down into the lower parts of the atmosphere, and do not disappear towards evening, *rain* may be expected. If loose fleecy patches of cloud begin to be thrown out from their surfaces, the rain is near at hand.

26. *Stratus.* — The *stratus*, as its name implies, is a widely-extended, continuous *layer* or sheet of cloud, increasing from below upwards. It is, besides, *the lowest sort of cloud*, its lower surface commonly resting on the earth. The stratus may be called the *cloud of night*, since it generally forms about sunset, grows denser during the night, and disappears about sunrise. It is *caused by the vapors which rise during the day, but towards evening fall to the earth with the falling temperature.* Since during night the cooling of the air begins on the ground, the

CLOUDS.

stratus first appears like a thin mist floating near the surface of the earth; it thence increases upwards as successive layers of the air are cooled below the point of saturation. It includes all those mists already described, which in the calm evening of a warm summer day form in the bottom of valleys and over low-lying grounds, and then spread upwards over the surrounding country like an inundation.

When the morning sun shines on the upper surface of the stratus cloud, it begins to be agitated and to heave up in different places into the rounded forms of the cumulus, and the whole of its lower surface begins to rise from the ground. As the heat increases, it continues to ascend, breaks up into detached masses, and soon disappears. This indicates a continuance of fine weather.

27. *Cirro-cumulus.*—This cloud is composed of well-defined, *small, roundish masses, lying near each other, and quite separated by intervals of sky.* It is formed from the cirrus cloud, the fibres of which break, and gather into these small masses. It is commonly known among sailors as a *mackerel sky.*

28. *Cirro-stratus.*—The *cirro-stratus* partakes partly of the characteristics of the cirrus and stratus. It consists of *long, thin, horizontal clouds, with bent or undulated edges,* and either separate or in groups. It is a marked precursor of storms.

29. *Cumulo-stratus.*—This cloud is formed by *the blending of the cirro-stratus with the cumulus,* either among its piled-up heaps, or spreading underneath its base as a horizontal layer. It is formed when the cumulus becomes surrounded with small fleecy clouds just before rain begins to fall, and also on the approach of thunder-storms.

30. *Cumulo-cirro-stratus, or Nimbus.*—This is the well-known *rain-cloud,* consisting of a cloud, or system of clouds, from which rain is falling. It sometimes has its origin in the cumulo-stratus, which increases till it overspreads the sky, and becomes black or bluish-black in color; but, this soon changing to gray, the nimbus is formed, and rain begins to fall.

Its name, *cumulo-cirro-stratus,* suggests the way in which it is more frequently formed. At a considerable height, a sheet of

ratus cloud is spread out, under which cumulus clouds on the windward; these rapidly increase and unite, form- continuous gray mass, from which the rain falls. The g-up of the lower gray mass indicates that the rain will ase.

n a rain-cloud is seen approaching at a distance, *cirri* to shoot out from its top in all directions; and the more s the rain-fall, the greater is the number of these cirri.

RAIN, SNOW, AND HAIL.

Rain. — Whatever lowers the temperature of the air may sidered as a cause of rain. It is *chiefly brought about ascent of air into the higher regions of the atmosphere.* air-currents are forced up into the higher parts of the here by colder, drier, and therefore heavier, wind-cur- which get beneath them. Ranges of mountains also their masses to the winds, so that the air forced up lopes is cooled, and its vapor condensed into showers or snow. Moist air-currents are also drawn up into the regions of the atmosphere over the area of least pressure centre of storms; and in such cases the rain-fall is gen- very heavy. The temperature of the air is lowered, and nount of the rain-fall increased, by those winds which the air to higher latitudes. This occurs in temperate s, or in those tracts traversed by the return trade-winds, in the north temperate zone blow from the south-west, the south temperate zone from the north-west. *The g and mixing of winds of different temperatures* is also of rain, since the several portions, when combined into nnot hold as much vapor as before. The rain-fall is also ed if the prevailing winds are directly from the sea, and erefore moist; but it is diminished if they have passed rge tracts of land, particularly mountain-ranges, and are re dry. The quantity of rain is influenced by *sandy*, which allow radiation, by day or night, to take im-

mediate effect in raising or depressing the temperature; and also by *forests*, which retard or counteract radiation.

Rain rarely or never falls in certain places, which are, on that account, called *rainless regions*; as, for example, the coast of Peru in South America, the Sahara in Africa, and the desert of Gobi, in Asia.

The Sahara is bounded on the north and on the south by ranges of mountains. When the north-east trade-wind strikes the northern range, a part of its vapor is condensed. As it moves southward, it reaches warmer latitudes, where there is a greater capacity for moisture. Since there are no opposing winds to force it upwards, it sweeps on across the vast sandy plain until it arrives at the southern mountains, where its vapor is precipitated in abundant rains. In the few spots in the desert where hills or mountains occur, there are occasional rains.

On the desert of Gobi, the prevailing winds are from the south-east, and are very dry, because they have precipitated nearly all their moisture in passing over the Himalaya Mountains.

The rainless district in Peru is caused by the Andes, which condense nearly all the vapor of the south-east trade-wind in copious rains on their eastern slopes.

On the other hand, in such places as Chili and Patagonia, it rains almost every day.

32. *Rain-fall within the Tropics.*—At places within the tropics, where the trade-winds blow regularly and steadily, the rain-fall is small. Since these winds come from higher latitudes, the temperature is increasing, and they are thus more likely to take up moisture than to part with it. Where, however, the trade-winds are forced up the slopes of mountain ranges, they bring rain in copious showers.

33. *The Region of Calms.*—This tropical belt (see page 235) is *the region of constant rains*. Here the sun almost invariably rises in a clear sky; but about midday clouds gather, and the whole face of the sky is soon covered with black clouds, which pour down prodigious quantities of rain. Towards evening the clouds disappear, the sun sets in a clear sky, and the nights

are serene and fine. The reason of this is, that the air, being greatly heated by the vertical rays of the sun, ascends, drawing with it all the vapor which the trade-winds have brought with them, and which has been largely increased by the rapid evaporation from the belt of calms; and this vapor is condensed as it rises. The rain is sometimes so copious that fresh water has been collected from the surface of the sea. As evening sets in, the surface of the earth and the air near it being cooled, the ascending currents cease, and the cooled air descends; the clouds are thus dissolved, and the sky continues clear till the returning heat of the following day.

34. *The Rain-fall of India.* — Over a great part of the tropics disturbing influences draw the trade-winds out of their course, and sometimes, as in the case of the monsoons, give rise to winds which blow from the opposite point of the compass. These winds affect the rain-fall of India, and but for them the eastern districts of Hindostan would be constantly deluged with rain, and the western districts constantly dry and arid. As it is, each part of India has its dry and wet seasons, summer being the wet season of the west and interior as far as the Himalaya, and winter the wet season of the east, and especially the south-east.

So far as known, *the heaviest annual rain-fall* at any place on the globe is 600 inches, on the Khasia Hills. About 500 inches of this fall in seven months, during the south-west monsoons. These hills face the Bay of Bengal, from which they are separated by only 200 miles of swamps and marshes. Hence the southerly winds not only arrive heavily laden with vapor from the Indian Ocean, but they get more moisture in passing over the 200 miles of swamp. They are, therefore, ready to burst in torrents, even before they are suddenly raised, by the hills they encounter, into the cooler regions of the atmosphere.

35. *Snow.* — Snow is the frozen moisture which falls from the clouds when the temperature is 32° or lower. The particles of which snow is composed are crystals, which are usually in the form of six-pointed stars. About 1,000 different kinds of snow-crystals have been already observed, a few of which are shown

in Figure 199. The forms of the crystals of the same fall of snow are generally similar to each other. Snow-flakes vary from an inch to $\frac{1}{100}$ of an inch in diameter, the largest being observed when the temperature is near 32°, and the smallest at very low temperatures.

The limit of the fall of snow at any time of the year coincides nearly with 30° N. latitude, which includes almost the whole of Europe. On traversing the Atlantic this line rises to 45°, but on nearing the American continent it descends to 33°; it rises in the west of America to 47°, and again falls to 40° in the Pacific. Snow is unknown at Gibraltar; at Paris, it falls 12 days on an average annually, and at St. Petersburg, 170 days.

The *white color* of snow is caused by the combining of the different prismatic rays which issue from the minute snow-crystals. When the crystals are looked at separately, some

Fig. 199.

appear red, others green, purple, and, in short, all the colors of the spectrum; but when a mass of snow is looked at, the different colors blend into white.

Red snow and *green snow* have been occasionally met with in the arctic regions and in other parts of the world. These colors are due to the presence of vegetable organisms, about $\frac{1}{1000}$ of an inch in diameter, which grow and flourish in the region of eternal snow.

From its loose texture, and from its containing about ten times its bulk of air, snow is a very bad conductor of heat; and thus is an admirable covering to preserve the earth from the effects of its own radiation. It not unfrequently happens in times of great cold, that the soil is 40° warmer than the surface

now which covers it. The flooding of rivers, from the of the snow on mountains in spring and summer, fertility into regions which would otherwise remain wastes.

ail. — Hailstones are generally of a conical or of a hape, and when cut across are found to be composed ıate layers of clear and opaque ice, enveloping a white ucleus. Less frequently they are composed of crystals g from the centre outwards. They vary much in size, ing as small as the smallest shot, while others are several n diameter. In August, 1813, hailstones the size of l upon the British army among the Pyrenees; the ısted twenty minutes, and was not accompanied with or lightning. June 4th, 1814, hail, from 13 to 15 inches eter, fell in Ohio. In the Orkney Islands, July 24th, ring thunder, a very remarkable shower of hail took he stones were as large as a goose's egg, and mixed ge masses of ice.

rigin of hail is not fully understood; but it appears to ed by a cold current of air forcing its way into a mass *ch warmer and nearly saturated*, the temperature of the ıass being below the freezing-point. The warm moist sily accounted for, since hail generally falls in summer ing the day; but it is difficult to account for the in- cold current which is sufficient to reduce the warm l mass below 32°.

ountainous regions, cold currents from the fields of ıshing down the sides of the mountains and mixing heated air of the valleys, are no doubt frequent causes and such places are peculiarly subject to hailstorms.

udden ascent of moist warm air into the upper regions mosphere, where a cold current prevails at the time, is, obability, a common cause of hail. This is confirmed ltry, close weather which generally precedes hailstorms, ıt but sudden fall of the barometer, the whirlwinds and g currents which accompany them, and the fall in the ure which follows after the storm has passed.

ATMOSPHERIC ELECTRICITY.

37. *Electricity in the Air.*—The identity of lightning and electricity was first suspected by Wall in 1708, but it was reserved to Franklin to prove it. In 1749, he suggested, as the mode of proof, the erection of pointed metallic conductors properly insulated. Acting on this suggestion, Dalibard erected near Paris a pointed iron rod, 40 feet in length, and insulated; and, on the 10th of May, 1752, obtained electrical sparks from it. In June of the same year, Franklin, impatient at the delay in erecting the spire for his pointed conductor, tried the experiment of obtaining electricity from the clouds by flying a kite. The kite was held by a hempen string, to the lower end of which a key was attached; and the whole was insulated by tying a silk ribbon to the key, the other end of the ribbon being attached to a post. On the approach of the thunder-cloud, he raised the kite, and soon the fibres of the hempen string began to repel each other; and, at last, when the rain had moistened the string, he had the satisfaction of drawing sparks from the key.

When the sky is cloudless, the electricity is always *positive;* but the intensity increases with the height.

When the sky is clouded, the electricity is *sometimes positive and sometimes negative*, according to the electrified condition of the clouds. In relation to the air, the earth's surface is always negative.

The electricity of the atmosphere is stronger in winter than in summer, increasing from June to January, and decreasing from January to June. It is subject to a double maximum and minimum each day.

38. *Sources of Atmospheric Electricity.*—(1) *Evaporation.*—Electricity is produced when *impure* water is evaporating, or water in which chemical decomposition is going on; none whatever being produced by the evaporation of pure water. Evaporation from water containing an alkali or a salt gives off negative electricity to the air, and leaves positive electricity

ind; but when the water contains acid, positive electricity is en off, and negative is left behind. Hence it is supposed t seas, lakes, and rivers are abundant sources of electricity, ticularly of the positive sort. (2) *Vegetation.*—The vegele kingdom is also a source of electricity; (*a*) from the evaption going on by which water is separated from the sap of plants, and (*b*) from the giving off of oxygen gas during day, and carbonic gas during the night. In these cases, sitive electricity arises from the plants, and negative is left hind. (3) *Combustion.*—During the process of burning, dies give off positive electricity, and become themselves negvely electrified. This is frequently seen on a grand scale ring volcanic eruptions. (4) *Friction.*—Wind, by the fricn it produces upon terrestrial objects, the particles of dust, d the watery particles which it carries with it, contributes to electricity of the air. Electricity is not generated if the isture be in the form of pure vapor.

39. *Effect of the Condensation of Vapor.*—When a great mulide of molecules of vapor are condensed by cold into a drop, snow-spangle, that drop probably collects and retains on its face the whole electricity of the molecules from which it is med. If a thousand such globules coalesce into one, the ctricity will be increased a thousand-fold, and, being spread irely over the surface, will have a tenfold tension. This w (which is Sir John Herschel's) explains the electricity obved in the lower stratum of air when *dew* is being deposited, d the highly electrical state of *fogs* and *clouds*. It also exins the annual fluctuation; for, since in winter the condenion of vapor is greater and more frequent than in summer, average quantity of electricity will be greater in winter.

40. *Thunder-storms.*—The thunder-storm probably originates, e cloud and rain, in *the condensation of vapor;* but the connsation is more copious and more rapid, so as to bring about accumulation of a sufficient quantity of electricity. If the ndensation is not copious, the electricity will be too weak; d if not sudden, it escapes before enough collects for a disarge.

Thunder-storms occur most frequently within the tropics, and diminish in frequency towards the poles. They are also more frequent in summer than in winter; during day than during night; after midday than before it; and in mountainous countries than in plains. Within the tropics they prevail most in the region of calms and during the rainy season; and least in arid deserts and during the dry season.

41. *Lightning.* — Arago has divided lightning into three kinds; *zigzag lightning*, *sheet lightning*, and *ball lightning*. When the electric flash darts through the air, it takes the path of least resistance; and, since the conducting power of different portions of the atmosphere is unequal, the lightning frequently appears *zigzag*. When branches are given off at different points of its course, the lightning is said to be *forked*. *Sheet lightning* is the most common, appearing as a glow of light illuminating the sky. The flashes often follow each other in quick succession, and the thunder which accompanies them is low and at a considerable distance. Analogous to this is *silent lightning*, often called *heat lightning*, which generally occurs during serene summer evenings, lighting up the sky for hours with repeated faint flashes, attended with no thunder. It is probable that this kind of lightning is almost always the reflection of the lightning of distant storms from the vapor of the upper regions of the atmosphere. *Ball lightning* is the least common. It appears as a globular mass, moving slowly or sometimes remaining stationary, and in a short time explodes with violence. It has not yet been satisfactorily explained. The duration of a flash of lightning, like that of an electric spark, is less than the thousandth part of a second. For this reason a wheel rotating so fast that the spokes are invisible will appear stationary when lighted up with the electric spark or by lightning.

42. *Thunder.* — Thunder is probably *the noise produced by the* ..us in which c... *fill the vacuum left by the lightning* along the effects ever being produc The sound emitted by flames is a familiar times o. ration from water ..ntend. Flashes of lightning frequently ative electricity to the air, length; and since the thunder is

ong its whole course nearly at the same instant, the
rolling noise arises from the different intervals of
s the sound to reach the ear. Reverberations from
from mountains frequently heighten the effect and
: peal. Thunder has not been heard at a greater
ın 14 miles from the flash.

ts of Lightning. — Electrical discharges generally
ıe air, or into other clouds less highly electrified;
only take place between the cloud and the earth.
er class innumerable lives have been destroyed, the
ees rent to pieces, heavy bodies displaced, iron and
tized, metals and rocks softened and fused, and com-
stances set on fire. When the thunderbolt falls upon
ıally produces *fulgurites*, or *fulminary tubes*, which
s tubes of various sizes vitrified within.

'n Shock. — The ***return shock*** sometimes proves fatal
:ings, even at great distances from the place of the
:harge. It is caused by the ***inductive*** action of the
loud, by which bodies become charged with the elec-
site to that of the cloud. When the cloud has dis-
electricity into the ground, the induction ceases, and
ıange of the bodies from the electrified to the neutral
:hem a severe shock.

tning-Rods. — The lightning-rod was invented by
ı 1755. The chief advantage gained by it is not
ects the building in case of a discharge by allow-
passage for the electric fluid to the earth; but by
gradually keeping up the communication, it tends
ı the electric equilibrium, and thus prevent a dis-
ıe best rods are made of copper, not less than three-
an inch thick, and pointed at the upper end. They
of one piece throughout, fastened vertically to the
building, and thence carried down into the ground.
extremity should part into two or three branches
rom the house, and carried far enough into the soil
ıter, or permanently moist earth. The conductor
connected with all metallic surfaces on the roof or

other parts of the building, in order to prevent the occ
of lateral discharges, or discharges from the conductor t
surfaces, which are often very destructive.

46. *St. Elmo's Fire.* — This meteor is the *Castor and*
of the ancients, and is frequently mentioned in classic
The finest and most beautiful displays occur at sea
storms, when it appears as a light resting on the mas
light which is seen on a point held near the conduct
electric machine explains St. Elmo's fire. It takes pl
the electricity of a cloud and that of the earth combi
flashes of lightning, but *slowly and continuously fro*
points.

47. *The Aurora Borealis.* — The *aurora borealis* is a
appearance in the northern sky. It is observed al
neighborhood of the south pole, and is there call
australis. When fully developed, the aurora consists
segment of a hazy or slaty appearance, surmounted l
of light, from which luminous *streamers* quiver an
wards. Several auroral arches are sometimes seen
Sometimes the streamers appear to unite near the ze
ing what is called the *corona* of the aurora, towards
dipping needle at the time points.

Auroras are very unequally distributed over the e
face. At Havana, but six have been recorded within
years. As we travel northwards from Cuba, they i
frequency and brilliancy; they rise higher in the he
oftener attain the zenith. If we travel northwards
meridian of Washington, we find, on an average, ne
allel of 40°, only ten auroras annually. Near the
42°, the average number is twenty annually; near
forty; and, near 50°, it is eighty. Between this poi
parallel of 62°, auroras are seen almost every nigh
the heavens, and as often to the south as the north
north, they are seldom seen except in the south, an
point they diminish in frequency and brilliancy as w
towards the pole. If we make a like comparison fo
ridian of St. Petersburg, we shall find a similar res

that the auroral region is situated farther northward than it is in America. Auroras are more frequent in the United States than they are in the same latitudes of Europe.

The aurora is of great extent, having been sometimes observed simultaneously in Europe and America. The height varies from about 45 to 500 miles above the earth.

48. *Relations of the Aurora to Magnetism.* — Many facts show a connection between the aurora and terrestrial magnetism. The magnetic needle is much agitated when the aurora is visible. When the arch is motionless, so is the needle; but as soon as streamers are shot out, its declination changes every moment, and this happens though the aurora does not appear at the place of observation, but is seen near the pole. It is probable that magnetic disturbances of the earth are due to the sun, but not to his heat and light; and that they are invariably accompanied by the aurora and by electric currents on the surface of the earth. The secular periods of *the sun's spots*, of the *variation of the magnetic needle*, and of the *frequency of auroras*, coincide in a remarkable way, indicating that these phenomena are regulated by astronomical causes.*

OPTICAL PHENOMENA.

49. *The Rainbow.* — The rainbow, in its most perfect form, consists of two colored arches projected upon falling rain on which the sun is shining from the opposite quarter of the heavens. The lower or inner arch is called the *primary* bow; the upper or outer, the *secondary* bow. Each contains all the colors of the spectrum, but the order of the colors in one is the reverse of that in the other. Red is outermost in the primary bow, and innermost in the secondary. The primary bow is the narrower and brighter of the two, and when it is of unusual brightness narrow red arches are seen just within it, called *supernumerary* bows. These are sometimes three or four in number, but they can be traced only a short distance. The

* See *Handbook of the Stars*, p. 91.

common centre of the bows is in a line drawn from the sun through the eye of the observer.

The rainbow is *produced by the refraction and reflection of the sunlight within the rain-drops*. Its *colors* are *due partially to the dispersion, and partially to the interference of the light thus refracted and reflected.*

Rainbows in the morning are always seen in the west, and indicate the advance of the rain-cloud from the west at the time that it is clear and bright in the east. Since the fall of rain at this time of the day when the temperature should be rising is an additional evidence of increasing moisture, a morning rainbow is a prognostic of a change to wet, stormy weather. On the contrary, a rainbow in the evening shows the passing of the rain-cloud to the east, and a clearing up in the west at the time of day when the temperature has begun to fall; thus further indicating a change from wet to dry weather. Hence the popular rhyme: —

> "A rainbow in the morning, —
> Sailors take warning;
> A rainbow at night
> Is the sailor's delight."

50. *Lunar Rainbows.* — Rainbows are also produced by the light of the moon falling on rain-drops, exactly in the same way as solar rainbows. They are by no means of rare occurrence. Owing to the feeble light of the moon, the bow is generally without colors; but when the sky is very clear and the moon is full, the prismatic colors appear, though in subdued splendor.

51. *Coronas.* — The corona is an appearance of faintly colored rings encircling the moon when seen behind the light, fleecy cloud of the cirro-cumulus. When the corona is perfect, the rings form several concentric circles, the blue prismatic color being nearer the centre than the red. When large, the ring has generally a whitish, nebulous appearance.

Coronas are also very frequently formed round the sun; but to see them it is necessary to look through smoked glass, or at the image of the sun reflected from still water.

thelia. — *Glories of light,* otherwise called *anthelia,* formed *opposite the sun,* are sometimes seen when the of an observer is cast on fog; and the shadow of his

Fig. 200.

Fig. 201.

Fig. 202.

Fig. 203.

Fig. 204. Fig. 205.

surrounded with the prismatic circles. The phenomenon n the polar regions whenever sunshine and fog occur at e time.

53. *Halos.* — Halos are circles of prismatic colors around the sun (Figures 200–203), or the moon (Figures 204 and 205), but they are not to be confounded with coronas. Halos are of comparatively rare occurrence; coronas, on the contrary, may be seen every time a light, fleecy cloud comes between us and the sun or moon. The structure of halos, as seen from the figures, is often very complicated, circle cutting circle with mathematical exactness, the circles being generally very large. The structure of the corona, on the other hand, is simple, the circles concentric, the inner one small, the diameter of the second being double, and that of the third treble, the diameter of the first. In halos, the red prismatic color is next the centre; in coronas, the blue. Halos are *formed by the refraction and reflection of the rays of light by the minute snow-crystals of the cirrus cloud;* while coronas arise from the interference of the rays passing on each side of the globules of vapor.

At the points where the circles of the halo intersect, images of the sun or moon generally appear, from the light concentrated at these points. The images of the sun are called *parhelia*, or *mock-suns;* and those of the moon, *paraselenæ*, or *mock-moons*. These also exhibit the prismatic colors of the halo.

54. *Colors of Clouds.* — The *red and golden* clouds which fire the western sky at sunset, are the accompaniment of cumulus clouds as they slowly sink, while dissolving, down into the lower and warmer parts of the atmosphere; and consequently they disappear from the sky shortly after sunset. Such sunsets are therefore prophetic of *fine weather*.

A *green* or *yellowish-green* sky, on the other hand, is one of the surest prognostics of *rain in summer*, and *snow in winter*. If, after a storm, the yellow tint becomes of a sickly green, more rain may be expected; but if it deepens into orange and red, the atmosphere is getting drier, and fine weather may be looked for.

It has been shown that high-pressure steam, while transparent, and *in the act of expansion*, readily absorbs the violet, blue, and part of the green rays, thus letting the yellow, orange, and red pass. It is found, also, that successive layers of air, with visible vapor diffused through them, separate the

itted light more and more perfectly from its more re-
le rays. The blue rays are first absorbed, then the yellow
id finally the red rays. It is in the lower layers of the
here that dust, smoke, watery vapor, and small rain-
are chiefly suspended. When the sun is high in the
s, the thickness of the vapor-screen between the sun
e eye has no perceptible action on the rays of light,
consequently appear white; but as the sun descends to
rizon, the thickness of the vapor is greatly increased,
: sunset, the light of the sun has to pass through 200
f the air in illuminating a cloud a mile above the earth.
as the rays fall more and more obliquely on the clouds,
ppear successively yellow, orange, and finally red. The
colors often seen at sunset are due to the fact that the
appear at different heights and in different parts of
r, so that various thicknesses of vapor are interposed
n them and the sun. At dawn, the clouds first appear
it; as the sun rises higher, the yellow light ceases to be
ed, and they appear orange, yellow, and finally white.
e changes are well described in Dante's *Purgatorio*: —

> The dawn was vanquishing the matin hour,
>   Which fled before it, so that from afar
>   I recognized the trembling of the sea. . . .
> Already had the sun the horizon reached, . . .
> So that the white and the vermilion cheeks
>   Of beautiful Aurora, where I was,
>   By too great age were changing into orange.
>
> *Longfellow's Translation.*

gh red dawn is a prognostic of settled weather, because
ness seen in clouds at a great height while the sun is yet
the horizon, may be occasioned by the great thickness
vapor-screen through which the rays must pass before
ig the clouds, and not by any excess of vapor in the air
But if the clouds be red and *lowering* in the morning, it
gn of rain; since, the thickness traversed by the rays
now much less, the red color must arise from an unusual
t of vapor in that stage of partial condensation, when the
ys are absorbed, and the yellow and red pass.

MOLECULAR MOTION AS MANIFESTED IN SOUND, LIGHT, HEAT, AND ELECTRICITY.

1. *Sound-waves.* — When water is agitated, the molecules vibrate in *sets*, one set moving upward while the next set is moving downward, thus giving rise to a *wave*.

When two sets of water-waves meet and cross, they are found at certain points to increase, and, at others, to diminish each other's volume. The former takes place when they meet *in the same phase*, — that is, when the hollow of one meets the hollow of the other, or the crest of one meets the crest of the other; while the latter occurs when they meet *in opposite phases*, — that is, when the crest of one meets the hollow of the other. If the waves are of the same size, they will in the one case destroy each other, and, in the other case, form a wave of double the height.

Now we have seen that two sounds may meet so as to destroy each other, or, as in the case of *beats*, so as alternately to increase and diminish each other. This must be because, in sonorous vibrations, the molecules vibrate in sets, so as to produce waves. When a string, for instance, vibrates, the air about it is alternately compressed and extended; and these compressions and extensions run on in the direction in which the sound travels, and constitute *sound-waves*. The molecules vibrate *longitudinally*, — that is, backward and forward; and not, as in the water-wave, *transversely*, — that is, at right angles to the direction in which the wave moves.

Sound-waves interfere so as to destroy each other when they meet in opposite phases; that is, when the compression of the one meets the extension of the other.

As the *pitch* of the sound *rises*, the vibrations become more rapid and the waves shorter; for the length of a sound-wave is the distance that the sound travels while the sounding body is making a single vibration.

Sounds give *beats* when they differ slightly in pitch. The waves which then flow out from the sounding bodies differ

slightly in length, and encounter each other alternately in the same and opposite phases.

2. *Reflection of Sound.* — The transmission of sound through air, or any other elastic medium, is best illustrated by a row of ivory balls. If the balls are all of the same size, each gives up all its motion to the next, and itself comes to rest. If one of the balls is larger than the next, it gives up only a part of its motion to it. If it is smaller than the next, it puts that in motion, and itself rebounds. When sound is travelling through the same medium, we have the condition of the balls of the same size. Each molecule gives up all its motion to the next, and itself comes to rest. When the sound meets a denser medium, we have the condition of a smaller ball striking against a larger one. The molecules of the denser medium are set vibrating, while those of the rarer medium rebound and transmit their motion backward, so that a part of the sound-wave is *reflected*. When the sound-wave meets a rarer medium, we have the condition of a larger ball striking a smaller one. The molecules forming the last layer of the denser medium retain a part of their motion, and transmit it back again to the molecules behind. In this case, also, the wave is partially reflected.

Hence, whenever a sound-wave meets a medium different in density from that in which it has been travelling, it is partially reflected and partially transmitted.

3. *Refraction of Sound.* — So long as sound is traversing the medium in which it originates, the advancing wave will have a spherical outline, since the sound travels with equal speed in all directions. But when the wave passes into a medium in which it travels at a different rate, its outline is changed. If it travels faster in the new medium, the portion of the wave in it will be rounded out, or become more convex; if it travels slower, it will be flattened, or become less convex. The direction in which any portion of a sound-wave is travelling will be represented by a line drawn perpendicular to the surface of that portion. Let *a b* (Figure 206) be a portion of a sound-wave moving in the direction of the arrow, and *a c* be the surface of a medium *O* of different density from *M*, in which the wave has

been moving. If the elasticity of O is such that the wave will move faster in it than in M, the portion a of the wave which enters O first will move on faster than the portion b while the

Fig. 206.

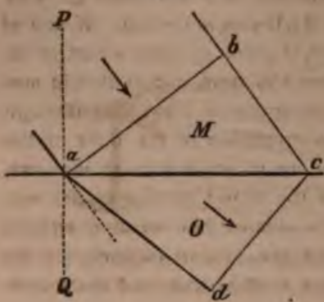
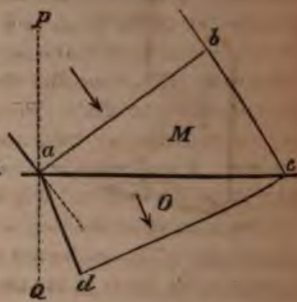


Fig. 207.



latter is moving in M. When $a\ b$ is wholly within O, the second arrow shows the direction in which it will be moving; and it will continue to move in this direction so long as it is wholly in this medium. When the direction of a wave is thus bent, it is said to be *refracted*. In this case, it is bent away from a perpendicular $P\ Q$ drawn to the surface of the medium O.

If the elasticity of O is such that the sound-wave moves slower in it than in M, the portion a of the wave (Figure 207), when it has entered O, moves slower than b while the latter is in M. In this case, it will be seen that the direction of the wave will be bent towards the perpendicular $P\ Q$.

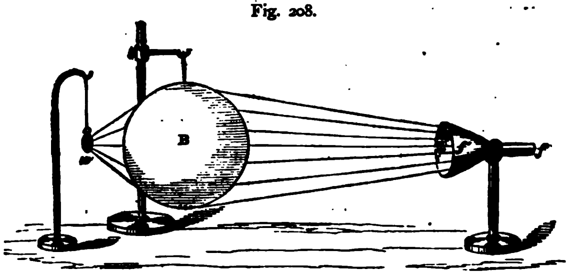
It is evident that, if $a\ b$ had not met the medium O obliquely, both ends of it would have entered O at the same time, and its direction would not have been changed.

We see, then, that when a sound-wave passes obliquely into a medium of different density, it is refracted, and that, if it travels more rapidly in the new medium, it will be bent away from a perpendicular drawn to the surface of that medium; while, if it travels less rapidly in the new medium, it will be bent towards a perpendicular drawn to its surface.

This refraction of a sound-wave has been shown by the ex-

ment illustrated in Figure 208. *B* is a collodion balloon
l with carbonic acid gas; *w* is a watch hung near it; and
a glass funnel. By placing the ear at *f*, and moving the

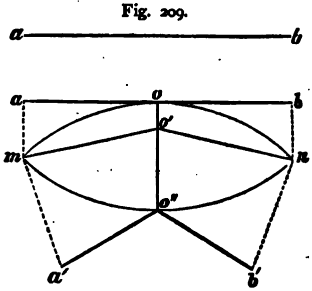
Fig. 208.



el about, a point will be found where the ticking of the
h will be louder than elsewhere. This shows that the sound-
es have been converged to that point.

igure 209 shows how the sound-waves are refracted in ing through the carbonic . *a b* is a portion of the d-wave. In passing into carbonic acid, — a medium hich it moves more slowly in air, — it is bent into orm of *m o′ n*. On passing rom the carbonic acid, it is still farther in the same di- on, and thus the two parts of vave are made to converge.

Fig. 209.



Light is propagated by Vibrations and Waves. — We have that *Newton's rings* are produced by the interference of of light. This interference of light leads us to the conclu- that light is also propagated by waves, which augment or oy each other, according as they meet in the same or site phases. These waves, of course, like those of wa sound, must be made up of vibrating molecules. Br traverse a vacuum as well as the air. The h transmits it, must exist in a vacuum

molecules of all transparent substances. This medium is called the *luminiferous ether*, or simply the *ether*. The existence of luminous waves is the only evidence of the existence of the ether, but this evidence is of such a kind that scientific men generally deem it conclusive. The ether fills not only the spaces between the earth and the sun and stars, but the spaces between the molecules of all bodies.

Since light, like sound, is propagated by vibrations, it is probable that it originates in vibrations. Moreover, in ordinary combustion, which is the most familiar source of light, the atoms of the oxygen in the air are rushing into combination with the atoms of the burning body; and the collision of these atoms will be very likely to set them vibrating.

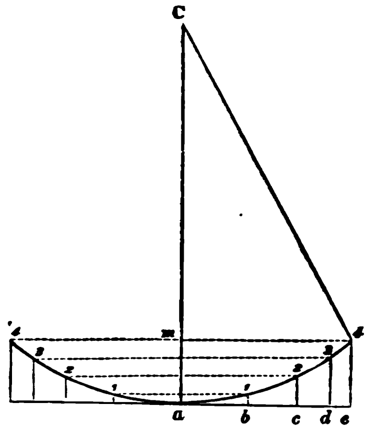
The vibrating molecules first communicate their vibrations to the molecules of the ether about them, and these transmit the vibrations with the enormous velocity of 190,000 miles a second.

When the vibrations meet a new medium, a part of them may pass on through the spaces among its molecules without disturbance, and thus some of the light is *transmitted*. A part of the vibrations may rebound, and thus some of the light is *reflected*. Another part may be taken up by the molecules of the medium, and thus some of the light is *absorbed*.

5. *The Length of the Luminous Wave.* — As the length of the sound-wave is the distance which sound travels while the sounding body is vibrating once, so the length of the luminous wave is the distance which light travels while the molecules of the luminous body are making one vibration. Of course the quicker the vibrations, the shorter the waves.

The length of the luminous waves can be found by means of *Newton's rings*. If the curved glass (Figure 210) be pressed down upon the plate beneath, and perpendicular rays of red light be allowed to fall upon it, the centre *a* will be black, and black rings will appear at 1, 2, 3, and 4. Since the centre is black, [illegible] waves reflected from the two surfaces must meet there in [illegible] phases, although the two surfaces are in contact. [illegible] a wave of light when reflected from a rarer [illegible]'s phase, while it does not when reflected from

Fig. 22a.



dium. The
ed from b
l a wave-
er than that
n 1, in order
es reflected
points may
osite phases,
a dark ring.
ve reflected
it evidently
he space 1 b
e 1 b must
ength of a
ive. For a
on, 2 c is a
; 3 d, a wave-length and a half; 4 e, two wave-
ow we can easily find the length of 4 e. 4 m is half
of the fourth dark ring, and is found by measure-
can also measure the radius 4 C, and 4 m C is a
triangle. In this triangle, we know the length of
nuse 4 C, and of the side 4 m; hence we can find
radius $C\,a - C\,m = a\,m = 4\,e$. If violet light be
urth ring is smaller, and 4 C is shorter. In this
ve-lengths in the following Table are found:—

	Length of waves in parts of an inch.	Number of waves in an inch.	Number of waves in a second.
d	.0000266	37,640	458,000,000,000,000
	.0000256	39,180	477,000,000,000,000
	.0000240	41,610	506,000,000,000,000
	.0000227	44,000	535,000,000,000,000
	.0000211	47,460	577,000,000,000,000
	.0000196	51,110	622,000,000,000,000
	.0000185	54,070	658,000,000,000,000
	.0000174	57,490	699,000,000,000,000
let	.0000167	59,750	727,000,000,000,000

According to Eisenlohr, the length of the waves in the extreme red ray is just double the length of the waves in the invisible rays beyond the violet. The whole range of rays, then, extends only over what is equivalent to a single octave in music.

The numbers in the last column of the above Table show the rate at which the molecules of a body must vibrate, in order to produce the different colors.

The molecules of certain substances seem to be capable of vibrating in all periods, and thus of producing white light; while those of other substances seem to be capable of vibrating only in particular periods, and therefore they produce light of different colors. It is seldom, however, that the vibrations of the molecules are limited to one period, and therefore that a luminous body gives out homogeneous light. We can now understand how it is that we can detect certain substances by the light they give.* Their particles can vibrate only in certain ways, and they of course cause the particles of ether nearest them to vibrate in the same way. The vibrations are sent on unchanged from particle to particle of the ether, and are ready at any point to reveal the nature of the substance in which they originated. The vibrations are so minute that it would seem impossible to find out their character, but the spectroscope enables us to do this with ease and accuracy.

When a number of strings of different lengths and tension are stretched in the air, as in the Æolian harp, they absorb all the vibrations accordant to their own which fall upon them, while they allow all the discordant ones to pass on. In much the same way, we must imagine the molecules of a body suspended in the ether, from which they absorb all accordant vibrations while they transmit all discordant ones.

Transparency is then synonymous with discordance, and opacity with accordance. This explains the fact that different substances absorb light of different colors, and also the fact that incandescent gases give out light of the same color as that which they absorb.

* See *Note* on § 209.

6. *Refraction of Light.*—The molecules of ether within a medium appear to be under some constraint, which increases with the density of the medium. This causes the wave to travel slower in a dense than in a rare medium; and therefore, on entering a denser medium, an oblique ray of light is bent towards a perpendicular to the surface of the medium, while on entering a rarer medium such a ray is bent away from the perpendicular. The quicker the vibrations, the more they are retarded, and the more the ray is refracted. It is owing to this unequal refrangibility that the colors are spread out into a spectrum when a ray of light passes through a prism.

7. *The Vibrations of Light are Transverse.*—We have seen that a polarized ray of light has *sides*. Now, if light were propagated, like sound, by *longitudinal* vibrations, it is difficult to see how a ray of it *could* have sides. If we take a long rubber cord fastened at one end, and alternately stretch and relax it, we have a rude representation of a ray of sound made up of longitudinal vibrations. The cord is evidently alike all round, and has no sides. But if we shake the cord so that it shall vibrate transversely to its length, we shall at once see that it is not the same above and below as it is to the right and the left; in other words, that it has *sides*. Hence we conclude that the luminous vibrations must be transverse. In an unpolarized ray the vibrations are transverse, but are executed in every plane; so that such a ray is alike all round. It is only by forcing the vibrations all into one plane that a ray can be polarized.

8. *Heat and Light are one and the same.*—We have seen that radiant heat and light are reflected, refracted, and dispersed in precisely the same way. It has also been found by difficult and delicate experiments that radiant heat is capable of *interference* and *polarization* in the same way as light. These facts lead to the conclusion that light and heat are the same thing, and the following fact proves this beyond a doubt.

We have learned that the solar spectrum is crossed by dark lines, known as *Fraunhofer's lines*. Now an examination of the spectrum with a very delicate thermopile has shown that these dark lines are also devoid of heat, and, furthermore, that simi-

lar dark or *cold* lines exist in the obscure part of the spectrum beyond the red end, where the heat is most intense. Again, these dark lines have been shown to be chemically inactive, and similar inactive lines are found beyond the violet end in the obscure *chemical* part of the spectrum. The existence of these blank lines throughout the whole length of the spectrum, in the obscure as well as in the luminous part, and the absence of both heat and chemical activity in the dark lines found in the luminous part, prove conclusively that the thermal, the luminous, and the chemical rays are one and the same thing.

Passing from the obscure end of the spectrum beyond the red to the obscure end beyond the violet, we meet with vibrations of greater and greater rapidity, but differing in nothing else. A portion of these vibrations at the lower or thermal end of the spectrum are too slow to be seen, but may be felt by the nerves which give us the sensation of heat. Another portion, including the luminous part of the spectrum, can be both seen and felt, and can also develop chemical action. A third portion, or those beyond the violet end, are too rapid to be seen or felt, but are able to cause chemical action. Luminous heat and light, then, are exactly the same thing; and obscure heat differs from luminous heat only as one color of the spectrum differs from another.

If there is need of further proof that obscure heat differs from light only in the rapidity of the vibration, it is furnished by an experiment of Dr. Draper's. He gradually raised the temperature of a platinum wire till it was of a white heat, and examined its spectrum throughout the process. At first the spectrum contained only the obscure thermal rays; then the least refrangible red rays appeared, followed in succession by the orange, yellow, green, blue, indigo, and violet; and after these came the obscure chemical rays.

9. *Electricity is a Mode of Molecular Motion akin to Heat.* Suppose the liquid used with the voltaic pair to be muria[illegible] acid. "The zinc plate, in virtue of the powerful affinity of [illegible] for chlorine, attracts the chlorine atoms, w[illegible] toward with immense velocity; and the sudden[illegible]

union of the chlorine with the zinc has the effect of
volley of atomic shot against the face of the plate.
atomic blows must give an impulse to the molecules
itself, which will be transmitted from molecule to
rough the material of the plate and the connecting
same way that a shock is transmitted along a line of
The electric current is merely "a wire or other con-
with innumerable lines of oscillating molecules."
nothing of the mode of the molecular motion in
conductor. It is apparently allied to heat, but is
roducing very different effects.
liar mode of molecular motion may also be de-
ieat, by magnetism, and by friction or percussion.
way, *heat* may be developed, not only by chemical
lso by friction and percussion.

Molecules of all Bodies are in Motion.—It would
that all the molecules of gross matter are in con-
on; and that, when acted upon by heat or other
molecules are made to perform their fundamental
ith greater energy, and to add to these higher and
ionics. Our organs of sense are instruments for
these vibrations and transmitting them to the
e they tell us nearly all that we know of the
rld.

CES AND CONVERSION OF ENERGY.

of Energy.—Every moving mass is said to have
amical energy. Every mass so situated that it can
the forces acting upon it is said to have *possible* or
ergy. The energy of a visible body in motion is
nical; that of moving molecules, or atoms, is called
atomic. The energy manifested in the bodies of
alled *muscular energy*, or *nerve-force.*

y, Cohesion, and Gravity tend to convert potential Energy.—When visible masses are separated, gravity
them together, and to convert their potential into

dynamical energy. When the *molecules* of a bo[dy]
as in melting or boiling, cohesion tends to dra[w]
again, and thus to convert their potential into
which appears as *heat*. Again, when the *atom[s]*
separated, affinity tends to bring them together
their potential into actual energy, which appear[s]
chemical action, as *heat* and *electricity*, and, in
heat and *nerve-force*.

13. *Mechanical Energy may be converted into*
have a familiar illustration of this in the lighting
match. A part of the energy used in rubbing the m[atch]
verted by the friction into heat, which ignites the p
Here there is a double transfer of energy. The musc[ular]
of the arm is converted into mechanical energy in th[e]
match, and a part of this into heat by the friction.

Before matches were invented, the flint and steel
for the same purpose. The steel was struck against
and the spark obtained was caught in tinder. A pa[rt]
mechanical energy of the steel appeared as heat in th[e]

Indians are said to obtain fire by vigorously rubbing
two pieces of dry wood. In this case, too, the heat is
but mechanical energy appearing in a new form.

Iron can be heated red-hot by hammering it. And, ge[n]
heat is developed by friction and percussion.

14. *All Mechanical Energy is ultimately converted into*
— When a falling body strikes the earth, it becomes heate[d]
this case, the whole energy of the body is converted into
When bodies are rubbed together, their energy, as we have
is converted into heat.

The energy of a running stream is gradually converted
heat by the friction against its banks and bed and amon[g]
particles. If it is made to turn the wheels of a factory
its way, the rubbing of the parts of the machinery ag[ainst]
each other and against the air, together with the various ki[nds]
of work done by the machinery, converts the mechanical ener[gy]
of the water-wheel in[to] ...

A railway train ... [stop]ped by the conversion of

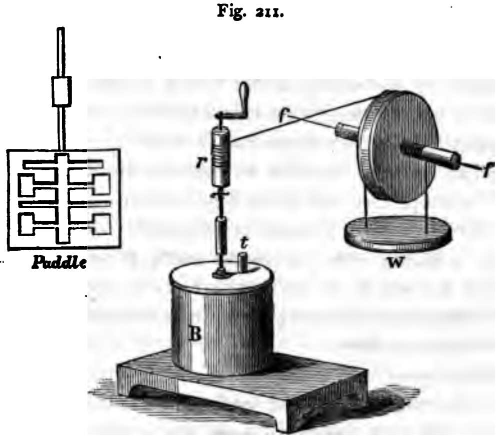
on into heat. When this has to be done quickly, the change ıstened by increasing the friction by means of the brakes. he other hand, in order to prevent the loss of energy while rain is in motion, the axles of the wheels are kept carefully ., that they may turn with as little friction as possible.

'hen unlike substances are rubbed together, a part of the gy is first converted into electricity, but ultimately into

. *When Mechanical Energy is converted into Heat, the same unt of Energy always gives rise to the same Amount of Heat.*

his was first shown by Joule, who began his experiments in , and continued them till 1849. He converted mechanical gy into heat by means of friction. He first examined cases ıe friction of solids against liquids. The apparatus used for purpose is shown in Figure 211. *B* is a cylindrical box ing the liquid. In the centre of the box is an upright axis,

Fig. 211.



hich are attached eight paddles, like the one shown in the re. These revolve between four stationary vanes, which ent the liquid from being carried round. The paddles are ed by means of the cord *r* and the weight *W*. The size he weight is such that it descends without acquiring any

velocity, and hence all its energy is expended in the friction of the paddles. The degree to which the liquid becomes heated by the friction, is shown by a thermometer at *t*. Knowing the weight of the liquid, its specific heat, and the rise of temperature during the experiment, the amount of heat generated can be readily calculated.

With this machine Joule found that, whatever the liquid be used, a weight of one pound falling through 772 feet, or 772 pounds falling one foot, generated heat enough to raise one pound of water one degree Fahrenheit in temperature, or one *unit of heat*, as it is called.

He also found that, when solids were rubbed together by the action of a falling weight, one pound falling through 772 feet generated a unit of heat. In this experiment, iron disks were made to rotate together, one against the other, in a vessel of mercury.

If a metallic disk be put into rapid rotation, and then brought between the poles of a powerful electro-magnet, it soon comes to rest. It will now be found very difficult to turn it, and it becomes heated as it rotates. Joule found in this case, as in the others, that, if the disk is turned by a falling weight, one pound descending 772 feet generates a unit of heat.

The force necessary to raise one pound one foot is called a *foot-pound*; and this is the same force which a pound acquires in falling one foot from a state of rest.

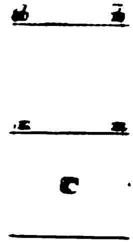
We see, then, that when mechanical energy is converted into heat, the same amount of energy always gives rise to the same amount of heat, and that 772 foot-pounds of mechanical force are equivalent to one unit of heat. For this reason, we call 772 foot-pounds the *mechanical equivalent of heat*.

16. *Heat may be converted into Mechanical Energy.*—The steam-engine is a contrivance for converting heat into mechanical energy. The heat converts the water into steam, and gives to this steam an expansive force; and this expansive force is made to move a piston, as explained on pages 91–93.

The animal body is a machine for converting the molecular energy developed by affinity into mechanical energy.

The Same Amount of Heat always gives rise to the Same Amount of Mechanical Energy. — In Figure 32, C is a box a foot square. Suppose a a to be a partition one foot from the bottom, so as to shut in a cubic foot of air. Suppose this partition to be immovable, and the air beneath to be heated. Its elastic force will be increased, but it cannot expand. We will next suppose that a a is movable, but without weight, and that the air beneath is heated as before. On raising its temperature 490°, its volume will be doubled, and a a will of course be raised one foot to b b. In raising a a one foot, it has had to raise the air above it. Now this air presses with a force of 15 pounds upon every square inch, or 15 × 144 = 2,160 pounds upon the whole surface. From the specific heat of air, we know that to raise the temperature of a cubic foot of air 490°, when it is free to expand, 9.5 units of heat are required.

Fig. 32.



But we have seen that a part of the heat which enters a body is used in expanding it, and a part in raising its temperature. In the above experiment, how much heat is used in raising the temperature? This is equivalent to asking how much heat is required to raise the cubic foot of air 490° when it is not allowed to expand. It has been found that the computed velocity of sound in air is less than its observed velocity, and that this is owing to the heat developed in the compressed portion of the sound-wave. From the ratio between the observed and the computed velocity, it is found that the specific heat of air when free to expand must be 1.42 of its heat when not allowed to expand. Hence the heat required to raise the temperature of a cubic foot of air 490°, when it is not allowed to expand, is found by the following proportion to be 6.7 units: —

$$1.42 : 1 = 9.5 : 6.7.$$

The amount of heat, then, used in expanding the air — that is, in raising 2,160 pounds one foot high — is 2.8 units. Dividing 2,160 by 2.8, we get 772, nearly.

Since there is no cohesion among the particles of air, the whole expansive force is used in raising the weight.

We see, then, that 772 foot-pounds of mechanical force are equivalent to a unit of heat, and that a unit of heat is equivalent to 772 foot-pounds of mechanical force.

We have seen that merely to *melt* a pound of ice at a temperature of 32° Fahrenheit requires 143 units of heat, which is equivalent to the force required to lift 110,396 pounds, or about 55 tons, a foot high. And to convert a pound of boiling water into steam requires 967 units of heat, equivalent to the force required to lift 746,524 pounds, or about 373 tons, a foot high. The force of gravity is almost as nothing compared with this molecular force.

The strength of affinity is shown by the amount of heat developed by the combination of oxygen and hydrogen. It is found that, when oxygen unites with one pound of hydrogen, 61,000 units of heat are generated. Hence the force which has combined the two gases is equal to $61,000 \times 772 = 47,092,000$ foot-pounds, or the force necessary to raise 23,546 tons a foot high, or to throw one ton to a height of more than four miles. A pound of carbon, in combining with oxygen, gives out about 14,500 units of heat, equivalent to 11,194,000 foot-pounds. We see, then, that the force even of cohesion is insignificant compared with that of affinity.

18. *Energy may be transmuted, but not destroyed.* — We have now seen that mechanical motion may be converted into the molecular motions of heat and electricity, and that these molecular motions may be converted into mechanical motion.

Energy, like matter, may assume a great variety of forms; but, like matter, it is wholly indestructible.

19. *Source of Energy.* — If left to itself, affinity would soon bring all dissimilar atoms together, and lock them up in compounds; cohesion would bring all the molecules of these compounds together, and lock them up in solids; and gravity would bring all these solids together, and hold them in its iron grasp; while the heat developed by these forces would be radiated into space, and our earth become one dreary waste, void of all signs of life and activity. What, then, is the source of the energy which is thus manifesting itself in Protean forms?

Let us consider, first, the energy developed by gravity. This energy is seen in the winds, the falling rain, and running streams. The atmosphere, on each side of the equator, is an immense wheel. The side of this wheel next the equator is continually expanded, and thus made lighter, by the heat of the sun. Hence gravity pulls down the colder and heavier side in the polar regions, and thus the wheel is made to turn. Were it not for the sun's heat, it would soon come to rest.

Again, the heat of the sun evaporates the waters of the ocean, and in their gaseous state they are swept round with the atmospheric wheel till they come to colder regions, where they are condensed, and fall to the earth as rain, and flow to the ocean in rivers. It is due, then, to the heat which comes to the earth in the sunbeam, that gravity can thus unceasingly manifest its energy.

The energy of chemical affinity, which is manifested in heat, light, and muscular force, is developed by its action between oxygen and carbon. How are these elements separated from carbonic acid, so that they may be reunited by affinity?

Place a leafy plant in a glass vessel, and let a current of carbonic acid stream over it in the dark, and no change takes place. Let the same gas stream over the plant in the sunshine, and a part of it will disappear, and be replaced by oxygen. When acted upon by the sunbeams, leaves of plants remove carbonic acid from the air, separate its carbon and oxygen, retain the former, and give the latter back to the air. When plants are consumed by combustion in our furnaces, and by respiration in our bodies, this oxygen combines with carbon and develops energy, which appears as mechanical force in our engines, and as muscular force in our bodies.

In the summer, when more sunshine than we need is poured upon the earth, a part of it is absorbed by the leaves of plants, and used to decompose carbonic acid, to build up the varied forms of vegetable life. In this way, the forests and the fields become vast storehouses of force which has been gathered from the sunbeam. When, therefore, we burn fuel in our stoves and food in our bodies, the light, heat, and muscular force developed

are only the reappearance in another form of the sunbeams stored up in plants.

But this process of gathering force from the sunlight has been going on for ages; and when we burn anthracite or bituminous coal, we are merely releasing the sunbeams imprisoned in plants which grew upon the earth before it became the dwelling-place of man.

The energy of affinity, then, like that of gravity, is nothing but transmuted sunshine.

The only form of energy known to us which does not come to the earth in the sunbeam is that developed by the ebb and flow of the tidal wave. This wave is dragged round the earth mainly by the attraction of the moon; and it acts as a brake upon the earth's rotation, since it is drawn from east to west while the earth is turning from west to east. The energy of this wave, then, is developed at the expense of the earth's motion on its axis; and it must tend to retard this motion, though to so slight a degree that the observations of thousands of years have not served to make it appreciable.

20. *The Amount of Heat given out by the Sun.* — Making allowance for the heat absorbed by the atmosphere, it has been calculated that the amount received by the earth during a year would be sufficient to melt a layer of ice 100 feet thick and covering the whole earth. But the sun radiates heat into space in every other direction as well as towards the earth; and if we conceive a hollow sphere to surround the sun at the distance of the earth, our planet would cover only $\frac{1}{2,300,000,000}$ of its surface. Hence the sun radiates into space 2,300,000,000 times as much heat as the earth receives.

21. *Source of the Sun's Heat.* — It has been supposed by some that the materials of the sun are undergoing combustion, and that this combustion develops the light and heat which it sends forth. There are, however, no substances known to us whose burning would produce so much heat for so long a time as we know the sun has been shining. Carbon is one of the most combustible substances with which we are acquainted; but if the sun, large as he is, were a mass of pure carbon, and were

ing at a rate sufficient to produce the light and heat that he ving out, he would be utterly consumed in 5,000 years. It s hardly possible, then, that the solar light and heat can be rated by ordinary combustion.

ıe of the most satisfactory theories of the origin of the solar is that developed in 1848 by a German physician, Mayer, known as the *meteoric* theory.

; have seen that a pound-weight which has fallen through eet will, when its motion is arrested, generate a unit of heat. , we know that a body falling that distance will acquire a ity of about 223 feet a second. Hence a pound ball moving a velocity of 223 feet a second will generate a unit of heat ı its motion is arrested. We know, too, that the velocity which a falling body strikes the ground is in proportion to square root of the height from which it falls; that is, in to double or treble its velocity, a body must fall from or nine times the height. A pound ball, then, moving a velocity of twice 223 feet a second will be able to generate ts of heat; one moving with thrice this velocity, 9 units of ; and so on. When, therefore, we know the weight of a and the speed with which it is moving, we can easily calc e how much heat will be generated on stopping it.

ere the earth's motion arrested, its elements would melt fervent heat, and most of them would be converted into r. Were the earth to fall into the sun, the heat generated ıe shock would be sufficient to keep up the solar light and for 95 years. We know that countless swarms of meteoric s are revolving in rings about the sun, and that they must oving in a resisting medium. If so, they must eventually rawn into the sun, and, from the velocity with which they strike, it has been shown that they could fall in sufficient ers to generate all the light and heat of the sun, without asing his magnitude enough to be detected, since accurate ures of his diameter were first made.

The Nebular Hypothesis. — According to Laplace, the rial of our solar system was once a nebulous mass of ex- ; tenuity, and the sun, moon, and planets were formed by

its gradual condensation. Let us suppose such a nebulous mass slowly rotating, and gradually cooling by radiation into space. As it cools, it must begin to contract; and as it contracts, its rotation must be quickened, since the matter at the surface must be moving faster than nearer the centre. It thus goes on contracting and rotating faster and faster, until the centrifugal tendency becomes so great that cohesion and gravity can no longer hold it together. A ring is then detached from the circumference, which continues to rotate by itself. The central mass goes on contracting and rotating with ever-increasing velocity, until a second ring is thrown off. In this way, ring after ring is detached, and all these rings continue to rotate round the central mass in the same direction. But the rings themselves would go on condensing, and at last they would be likely to break up, each forming one or several globular masses. These would, of course, all revolve about the central mass in the same direction, and their condensation would cause them to rotate on their axis; and it has been proved that, with the exception of one or two of the outer ones, they must all rotate on their axis in the same direction in which they revolve in their orbits.

But as these masses condensed, their rotation would be accelerated, and they would be likely to throw off rings, which would either remain as rings, or be condensed into globes.

The central mass, of course, forms the sun; the rings which it throws off, the planets; and the rings thrown off by the planets, the moons. In the case of Saturn, a part of the rings still remain uncondensed, while a part appear as moons.

The rings thrown off by the central mass usually condensed into one body, but, in the case of the minor planets and the meteoric rings, into many.

23. *Helmholtz's Theory of Solar Heat.* — Helmholtz has made the nebular hypothesis the basis of his theory of solar heat, an account of which is given by Tyndall as follows: —

"He starts from the nebular hypothesis of Laplace, and, assuming the nebulous matter in the first instance to have been of extreme tenuity, he determines the amount of heat generated

by its condensation to the present solar system. Supposing the specific heat of the condensing mass to be the same as that of water, then the heat of condensation would be sufficient to raise their temperature 28,000,000° Centigrade. By far the greater part of this heat was wasted ages ago in space. . . . Helmholtz supposes this condensation to continue; that a virtual falling down of the superficial portions of the sun towards the centre still takes place, a continual development of heat being the result. However this may be, he shows by calculation that the shrinking of the sun's diameter by .0001 of its present length would generate an amount of heat competent to cover the solar emission for 2,000 years; while the shrinking of the sun from its present mean density to that of the earth would have its equivalent in an amount of heat competent to cover the present solar emission for 17,000,000 of years."

Mayer's theory is evidently not inconsistent with that of Helmholtz, but supplementary to it. The former merely assumes that the meteors and planets, which were thrown off from the nebulous mass as it condensed, are slowly falling into it again. When these shall all have fallen into it, and the condensation shall have ceased, our sun will cease to shine, like many other stars which have disappeared from the heavens.

FRENCH WEIGHTS AND MEASURES.

The names of the *higher* orders of units, or the *multiples* of the standard unit, are formed from the name of the *standard unit* (the *mètre*, *litre*, etc.), by means of prefixes taken from the Greek numerals; namely, *déca-* (10), *hecto-* (100), *kilo-* (1,000).

The names of the *lower* orders of units, or the *subdivisions* of the standard unit, are formed in a similar manner by means of prefixes taken from the *Latin* numerals; namely, *déci-* (10), *centi-* (100), *milli-* (1,000).

TABLE OF LINEAR MEASURE.

10 millimètres	= 1 centimètre	= 0.3937 inch.
10 centimètres	= 1 décimètre	= 3.937 "
10 décimètres	= 1 *mètre*	= 39.37 "
10 mètres	= 1 décamètre	= 393.7 "
10 décamètres	= 1 hectomètre	= 328 ft. 1 inch.
10 hectomètres	= 1 kilomètre	= 3280 " 10 "

TABLE OF MEASURES OF SURFACE.

100 centiares	= 1 *are*	= 119.6 square yards.
100 ares	= 1 hectare	= 2.471 acres.

The *centiare* is a *square mètre*, or 1,550 square inches.

TABLE OF MEASURES OF CAPACITY.

10 millilitres	= 1 centilitre	= 0.6102 cubic inches.
10 centilitres	= 1 décilitre	= 6.1022 " "
10 décilitres	= 1 *litre*	= 1.0567 wine quarts.
10 litres	= 1 décalitre	= 2.6417 " gallons.
10 décalitres	= 1 hectolitre	= 26.417 " "
10 hectolitres	= 1 kilolitre	= 264.17 " "

The *kilolitre* is a *cubic mètre*, and is also called a *stère*. The *décastère* = 10 stères.

TABLE OF WEIGHTS.

10 milligrammes	= 1 centigramme	= 0.1543 grains.
10 centigrammes	= 1 décigramme	= 1.5432 "
10 décigrammes	= 1 *gramme*	= 15.432 "
10 grammes	= 1 décagramme	= 0.3527 oz. avoirdupois.
10 décagrammes	= 1 hectogramme	= 3.5274 " "
10 hectogrammes	= 1 kilogramme	= 2.2046 pounds "

The *millier* or *tonneau* is equal to 1,000,000 grammes, or 2204.6 pounds avoirdupois.

☞ The English equivalents given above are those which were established by Congress, in July, 1866, and are sufficiently accurate for all practical purposes.

PROBLEMS.

Teachers can use either the English or the French weights and measures. The French weights are not equivalents of the English, unless the nature of [illegible] requires it.

[illegible]GHT OF LIQUIDS.—1. A glass flask, when full of water, [illegible] 9 ounces (580 grammes). The flask itself weighs 4.1 (84 grammes). How many ounces (grammes) of water [illegible]e flask hold?

[illegible]he same flask, when full of mercury, weighs 69.1 ounces, [illegible] grammes). How many ounces (grammes) of mercury [illegible] hold?

[illegible]he same flask, full of alcohol, weighs 8 ounces (160 [illegible]es). How many ounces (grammes) of alcohol does it [illegible]

[illegible]he same flask, full of sulphuric acid, weighs 11 ounces [illegible]rammes). How many ounces (grammes) of sulphuric [illegible]oes it hold?

PRESSURE WHICH LIQUIDS EXERT BY REASON OF THEIR [illegible]T.—In these problems, it is assumed that in liquids the [illegible]re increases at exactly the same rate as the depth.

[illegible]hen water is one foot (centimetre) deep in a vessel, it [illegible] a pressure of 62.5 lbs. (one gramme) on every square [illegible]entimetre) of surface at the bottom of the vessel. What [illegible] be the pressure exerted upon every square foot (centi[illegible] of surface at the bottom, if the water in the vessel were [illegible](centimetres) deep?

[illegible]hat would be the pressure upon 9 square feet (decimetres) [illegible]face at the bottom, if the liquid were 6 feet (centimetres) [illegible]

[illegible]hat upon 13 square feet (decimetres) at the bottom, if [illegible]uid were 7.5 feet (17 centimetres) deep?

[illegible] closed vessel is 9 inches (3 decimetres) deep, and has a [illegible]rojecting from the top to the height of one yard (metre). [illegible]ottom of the vessel has a surface of 100 square inches (50 [illegible] decimetres), and the vessel is filled with water to the top

of the tube. What is the whole pressure upon the bottom of the vessel?

9. What would be the pressure upon a square inch (centimetre) of surface on the side of the above vessel, the centre of the surface being 3 inches (centimetres) from the bottom?

10. What would be the pressure upon a square inch (centimetre) of surface at the top of the vessel?

11. What would be the pressure upon the whole upper surface of the vessel, supposing it to contain 100 square inches (50 square decimetres)?

12. A cubical vessel, every side of which is a square yard (metre), is filled with water. What would be the pressure upon its bottom?

13. What would be the pressure upon each of its sides? *

14. Suppose the top of the above vessel were closed, and a tube one yard (metre) in length were inserted into it, and were filled with water, what would be the pressure exerted upon the top of the vessel?

15. What would be the pressure upon the bottom of the vessel when the tube is full of water?

16. What would be the pressure upon the sides of the vessel in the last case?

THE HYDROSTATIC PRESS. — 17. The end of the small piston in a hydrostatic press has a surface of 10 square inches (centimetres); and the end of the large piston a surface of a square foot (decimetre). A pressure of 10 pounds (kilogrammes) upon the small piston would bring what pressure to bear upon the large piston?

18. If the small piston be the same as above, and the end of the large piston contain a square yard (metre) of surface, 5 pounds (kilogrammes) upon the small piston will cause what pressure to be brought to bear upon the end of the large piston?

19. A pressure of 75 pounds (kilogrammes) on the small

* To find the pressure upon any surface at the sides of a vessel, take the *average* depth of the surface, that is, the distance from the top of the water to the middle of that surface.

piston would cause what pressure to be exerted upon the end of the large piston?

THE BUOYANCY OF LIQUIDS.—A cubic inch of water weighs 252.458 grains, the grain being $\frac{1}{7000}$ of a pound avoirdupois. For ordinary calculations, a cubic foot of water may be assumed to weigh 1,000 ounces, or 62.5 pounds, avoirdupois. A cubic centimetre of water weighs 1 gramme.

20. A body weighs 50 pounds (kilogrammes) in air, and has a bulk of 432 cubic inches (40 cubic decimetres). How much does it weigh in water?

21. A stone weighs 80 pounds (kilogrammes) in the air, and 55 pounds (kilogrammes) in water. What is its bulk?

22. A hollow vessel of copper weighs one pound (kilogramme). What must be its bulk in order that it may just float in water?

23. A hollow vessel of iron weighs 15 pounds (kilogrammes). What must be its bulk in order that it may sink one-half in water?

24. A boat displaces 12 cubic yards (metres) of water. What is its weight?

SPECIFIC GRAVITY.—25. A body weighs 15 pounds (150 hectogrammes) in air, and weighs 2 pounds (2 kilogrammes) in water. What is the weight of a bulk of water equal to that of the body?

26. A flask full of water weighs 6.2 ounces (62 grammes): a piece of lead weighs 44 ounces (44 decagrammes) in the air. It is put into the flask, and the flask is filled with water. It is found that the lead and water together weigh 46.2 ounces (462 grammes). What is the weight of a bulk of water equal to that of the lead?

27. A piece of lead weighs 3 pounds, 8 ounces (56 grammes) in the air, and 3 pounds, 3 ounces (51 grammes) in water. What is the specific gravity of lead?

28. A flask holds 15 ounces (75 grammes) of water: a lump of copper, which weighs 1 pound (160 grammes) in the air, is put into the flask, and it is found that the water and the copper together weigh 1 pound, 5.9 ounces (219 grammes). What is the specific gravity of copper?

29. The specific gravity of iron is 7.8. What weight of water will 45 pounds (kilogrammes) of iron displace?

30. The specific gravity of zinc is 7.2. What is the bulk of 90 pounds (kilogrammes) of zinc?

31. A piece of wood which weighs 5 ounces (25 grammes) in the air, is fastened to a piece of iron whose weight is 1 pound (80 grammes); and on immersing both in water and weighing them, it is found that they together weigh 9 ounces (45 grammes). What is the weight of the water displaced by the wood?

32. A piece of wood, weighing 4.2 ounces (42 grammes), is fastened to a piece of zinc weighing 8.6 ounces (86 grammes), and both are weighed under water, and are found to weigh 3.4 ounces (34 grammes). What is the specific gravity of the wood?

33. A flask weighing 2 ounces (20 grammes) weighs 2 pounds, 11 ounces (430 grammes) when full of water, and 34 pounds, 11.5 ounces (5555 grammes) when full of mercury. What is the specific gravity of mercury?

34. A hydrometer weighing 5 ounces (50 grammes) requires a weight of 8 ounces (80 grammes) to sink it to the neck in water, and a weight of 13.5 ounces (135 grammes) to sink it to the same depth in sulphuric acid. What is the specific gravity of sulphuric acid?

35. A vessel holds 100 pounds (kilogrammes) of water. How much mercury would it hold?

36. How much alcohol will it hold, if the specific gravity of alcohol is .79?

WEIGHT OF GASES. — The *specific gravity* of a gas is *its weight compared with that of an equal bulk of atmospheric air.*

37. A glass globe of the capacity of 61 cubic inches (one litre) weighs 29.27 ounces (83 grammes) after the air has been exhausted from it; and 29.73 ounces (84.292 grammes) when full of air. What is the weight of 61 cubic inches (a litre) of air?

38. The same globe, when full of ammonia gas, weighs 29.54 ounces (83.759 grammes). What is the weight of 61 cubic inches (a litre) of ammonia gas?

39. The same flask, when full of carbonic acid, weighs 29.96 ounces (84.964 grammes). What is the weight of 61 cubic inches (a litre) of carbonic acid?

40. The same flask, full of hydrogen, weighs 29.3 ounces (83.089 grammes). What is the weight of 61 cubic inches (a litre) of hydrogen?

41. What is the specific gravity of ammonia gas?

42. What is the specific gravity of carbonic acid?

43. What is the specific gravity of hydrogen?

44. A vessel of the capacity of 34 cubic feet (985 litres) would hold how many ounces (grammes) of air? of carbonic acid? of hydrogen?

Pressure caused by the Weight of Gases. — The atmospheric pressure (74) is about one kilogramme upon every square centimetre of surface at the level of the sea.

45. The body of an ordinary-sized man has a surface of about 2,340 square inches (16,000 square centimetres). How many pounds (kilogrammes) of pressure does the atmosphere exert upon a man's body?

46. A room is 12 yards (metres) long, 9 yards (metres) wide, and 5 yards (metres) high. How many pounds (kilogrammes) of pressure does the atmosphere exert upon the floor of the room?

47. How many pounds (kilogrammes) of pressure does it exert upon each end of the room? How many on each side?

48. How many pounds (kilogrammes) of air does the room contain?

49. The atmospheric pressure will balance a column of mercury 30 inches (76 centimetres) high, and the specific gravity of mercury is 13.5. It will balance a column of water how many feet (metres) high?

50. If water is to be raised 45 feet (1,200 centimetres) high by means of the lifting-pump, how much of this distance must the water be lifted?

51. Water is to be carried over a hill 68 feet (1,350 centimetres) high? Can it be done by means of the siphon? Why?

Buoyancy of Gases. — 52. A block of wood has a bulk of 900 cubic yards (metres). How much is it buoyed up in the air?

53. A balloon when filled with gas weighs 1,000 pounds (500 kilogrammes). How many cubic feet (litres) of bulk must it have, in order that it may just float in the air?

54. A balloon has a bulk of 1,000 cubic yards (metres), and weighs 50 pounds (25 kilogrammes). It is filled with coal-gas, whose specific gravity is .6. By how many kilogrammes of pressure is it forced upward? If a car, which, with all its fixtures, weighs 96 pounds (48 kilogrammes), be attached to the balloon, with what pressure will the whole be forced upward?

SECOND LAW OF MOTION. — Gravity causes a body to fall from a state of rest 4.9 metres in a second, and increases its velocity 9.8 metres in a second (95).

55. A body falls from a state of rest. What will be its velocity at the end of the third second?

56. A body is thrown downward with a velocity of 50 yards (metres) a second. What will be its velocity at the end of 7 seconds?

57. A body is thrown downward with a velocity of 23 yards (metres) a second. What will be its velocity at the end of 9 seconds?

58. A body is thrown upward with a velocity of 42 yards (metres) a second. What will be its velocity at the end of 4 seconds? At the end of 6 seconds?

59. A body is thrown upward with a velocity of 98 yards (metres) a second? How long will it continue to rise?

60. How high will the above body rise?

61. How far will it rise the first 3 seconds?

62. How far will it rise the last 3 seconds?

63. How far will it rise from the beginning of the 3d to the end of the 8th second.

64. Two bodies are thrown upward, one with a velocity of 224 feet (68.6 metres) a second, and the other with a velocity of 448 feet (137.2 metres) a second. How many seconds will it be before each begins to fall?

65. To what height would each rise?

66. A ball falls from a state of rest, and reaches the earth in 12 seconds. With what velocity does it strike the earth?

67. From what height did the ball in the last example fall?

68. How far did it fall the first 5 seconds?

69. How far did it fall the last 5 seconds?

70. How far did it fall from the beginning of the 3d to the end of the 5th second?

71. How far did it fall from the beginning of the 8th to the end of the 11th second?

72. A ball is thrown downward with a velocity of 125 yards (metres) a second, and reaches the earth at the end of 7 seconds. What is its velocity on reaching the earth?

73. From what height was the ball in the last example thrown?

74. Through what distance did it pass from the beginning of the 3d to the end of the 6th second?

75. A stone falls from a state of rest, and is 4 seconds in reaching the earth. With what velocity does it strike the earth? Through what distance does it fall?

76. If the stone had reached the earth in 8 seconds, what velocity would it have acquired, and through what distance would it have fallen?

77. If the stone had reached the earth at the end of 12 seconds, with what velocity would it have reached the earth, and through what distance would it have fallen?*

78. A body in falling from a state of rest through 16 feet (4.9 metres) acquires a velocity of 32 feet (9.8 metres) a second. Through what distance must it fall in order to double this velocity? To treble this velocity?

79. A stone falls from a height of 64 feet (19.6 metres). With what velocity does it reach the earth?

THIRD LAW OF MOTION. — To find the *momentum* of a body, *multiply its weight in pounds (grammes) by its velocity in feet (metres).*

* When we know the velocity a body acquires in falling through a certain distance a, and we wish to know what velocity it will acquire in falling through any other distance b, divide the distance b by a, extract the square root of the quotient, and multiply the velocity the body acquires in falling through the distance a by the number thus obtained. If, on the other hand, we wish to know how far the body must fall to acquire any velocity c, divide the velocity c by the velocity a body acquires in falling through the distance a, square the quotient, and multiply the distance a by this number.

80. A body weighs 50 pounds (kilogrammes), and is moving at the rate of 12 yards (metres) a second. What is its momentum?

81. The same body is moving at the rate of 5 yards (metres) a second. What is its momentum?

82. With what velocity must a body weighing 6 pounds (grammes) move, in order to have the same momentum as a body weighing 10,000 pounds (500 kilogrammes), and moving at the rate of 2 yards (metres) a second?

83. A certain force gives to a body weighing 45 pounds (kilogrammes) a velocity of 9 yards (metres) a second. What velocity would the same force give to a body weighing 3 ounces (grammes)?

MACHINES.—84. In a lever, the short arm is 5 inches (decimetres) long, and the long arm 61 inches (decimetres) long. How far will the end of the long arm move while the end of the short arm moves through 3 inches (centimetres)?

85. In a lever, the short arm is 2 yards (metres) long, and the long one 15 feet (50 decimetres) long. A power of 2 pounds (kilogrammes) is applied to the end of the long arm. What weight at the end of the short arm will it balance?

86. While the weight in the last example is moving through 3 inches (decimetres), how far will the power move?

87. A weight of 5 pounds (60 decagrammes) is applied at the end of the long arm of the lever in the above example. What power must be applied at the end of the short arm to balance it?

88. In a wheel and axle, the circumference of the wheel is 4 yards (metres) and that of the axle 9 inches (30 centimetres). What weight will a power of 3 pounds (grammes) balance?

89. In a train of wheels, a power of 1 ounce (gramme) balances a weight of 450 pounds (43 kilogrammes). What distance must the power move through while the weight moves through 12 feet (50 decimetres)?

90. In a system of pulleys, a power of 1 ounce (gramme) balances a weight of 1,200 pounds (245 kilogrammes). How far will the weight move while the power is moving through 1 foot (metre)?

NOTES ON EXPERIMENTS.

In the following notes, we shall mention all the apparatus necessary for performing the more important experiments in this book. If the teacher cannot procure all the apparatus, he can make a selection from the list according to his means. If he is able to add to the list, he can select from the apparatus mentioned in the book, but not included here. In the larger *Natural Philosophy* of the *Cambridge Physics*, many additional pieces of apparatus are described, and many additional experiments and illustrations are given. The teacher should have that book for reference and for use in oral instruction. See also works mentioned in the Preface of that book.

COHESION. — 1. Ring and ball, for § 3. An old-fashioned *pyrometer* (with dial and index) is perhaps better for showing contraction and expansion by change of temperature.

2. Two half-pint flasks, provided with rubber corks, through which glass tubes of small bore pass. These can be used in all cases, instead of a bulb with projecting tube; and the flasks will be useful for many other experiments.

3. A pair of lead hemispheres, for § 9.

4. Two evaporating dishes; for making crystals, and for other purposes.

5. A crucible, for sulphur crystals.

6. A dozen *Rupert's drops*.

7. Two glass two-quart jars, with ground mouths and plates to cover them.

8. A dropping-tube. This is to be used in the experiment in § 21, which we advise all teachers to try. With a little care, the mixture of alcohol and water can be made of such density that the oil will neither sink nor rise in it. It can be tested from time to time with a drop of oil. When it is just right, fill the bulb and stem of the dropping-tube with sweet oil, close the top with the thumb, and put the small end into the centre of the mixture. Remove the thumb, and keep the tube steady till the oil runs out.

If the mixture is made in one of the two-quart jars (No. 7) and covered, the sphere of oil can be kept for a number of days.

9. Half a dozen 6-inch test-tubes, one of which is to have a rubber cork and tube for the experiment in § 22.

10. A U-tube and nipper-tap, for §§ 23 and 24.

11. Wooden retort-holder, for holding U-tube and for other purposes.

12. Eight pounds of mercury for experiments with U-tube, and also for experiments in §§ 27, 36, 40, and 72.

ADHESION. — 1. Hydrostatic balance, and glass disk with hook; for experiment in § 27, and also in § 62.

2. A shallow glass dish.

3. Two small glass funnels, and a pack of filters.

4. A set of capillary tubes.

5. Two glass cylinders: one, 1 inch in diameter and 5 inches deep; the other, 1½ in diameter and 7 deep. These should have ground mouths and ground-glass plates for covers. The small one is to be used for §§ 36 and 40, and the large one for § 38.

For method of filling the cylinder with ammonia, see *Handbook of Chemistry*, page 189, § 23. Do not fail to try these experiments.

6. Glass tube, about 10 inches long; to be used, with a small funnel, for experiment in § 38, which is simple and striking.

7. Bladder and tube, for § 39. The tube should have as small a bore as possible, that the rise of the liquid may be quickly seen. With proper care, the alcohol can be poured in through a small funnel.

8. Bottles and tube, for § 42.

For the preparation of hydrogen, see *Handbook of Chemistry*, page 182, § 11. For preparation of carbonic acid, see same book, page 29, § 42. For the method of filling the bottles with the gases, see same book, page 181, § 1.

The upper bottle and tube should be together filled with hydrogen. The end of the tube should then be closed with the thumb and inserted into the other bottle. The cork of the lower bottle should be left on the tube.

9. Cup and tube, for § 43. Instead of a bell-jar, the jar in No. 7 may be used.

The two last experiments are very striking, and can be easily performed.

Much of the apparatus described thus far is the same as that used for the *Handbook of Chemistry*. For the last two experiments, the bottle generator and hydrogen generator described in that book (page 182, § 6 and § 11) will be needed.

MECHANICS. — 1. Balls and rods represented in Figure 19. Any of the ordinary pieces of apparatus for illustrating centre of gravity will answer the purpose.

2. Bottle with tubes (Figure 26).

3. Apparatus shown in Figure 27.

4. Working model of hydrostatic press.

5. Cylinder and cup, for § 62.

6. A hydrometer (Figure 34).

7. An air-pump with receiver. For all the experiments in this book, a table air-pump (Figure 39) will answer.

8. Magdeburg hemispheres.

9. Hand-glass.

10. Weight-lifter.

11. Small rubber bag.

12. Barometer tube.

13. Model of lifting and force pumps.

14. Glass siphon.

15. Tantalus's cup.

16. Apparatus for throwing and dropping a ball at the same time, for § 92.

17. Guinea and feather tube.

18. Three ivory balls and a lead ball, for §§ 104 and 105. These experiments should be performed.

19. Models of lever and compound lever.

20. Model of wheel and axle.

21. Models of pulleys. Those shown in Figures 70 and 73 will do.

Other models of simple machines are desirable, but not so well adapted to class experiments.

22. Model of Barker's mill.

SOUND. — 1. Bell, for § 144. A sliding-rod is not necessary, as the bell can be rung by tilting the pump.

2. A gyroscope for § 155. If one has an ordinary gyroscope, a toothed wheel can be readily fitted to its axle.

3. Three large tuning-forks, and two sounding-boxes for the same. Two of the forks should be of the same pitch.

These are the most important pieces of apparatus for sound. By means of them we illustrate sympathetic vibrations (§ 168), interference (169), beats (170), and resonance (180, 184). To illustrate *beats*, the two forks in unison are to be used, one of them being loaded with wax, as described in § 168.

4. Sonometer and strings. This also is a very important piece of apparatus.

5. Vibrating plate, for § 164.

6. A violin bow.

7. Brass rods, for § 178.

8. Brass rods and frame (Figure 103). The experiment is a very striking one.

9. A resonant jar, for § 180. The nitric-oxide jar (*Handbook of Chemistry*, page 184, § 18) is just right for the purpose.

10. Three glass tubes, for § 182.

11. Three organ-pipes, of the same pitch as the three tuning-forks.

12. A reed pipe.

13. Jet and tube for singing flame.

LIGHT. — 1. An oxy-hydrogen lantern. On the whole, the best method of illustrating radiant light and heat is by means of the lime light. The lantern should be provided with lenses for making the rays parallel, and with two diaphragms, one having a circular aperture, and the other a longitudinal one. The magnesium light is very good for the experiments in *Light*, but is of no use for those in *Heat*.

2. Two 25-gallon gas-bags, for use with the lime light. For the preparation of the oxygen, see *Handbook of Chemistry*, page 10, § 10, and page 187, § 9.

3. An adjustable stand for holding prisms, etc.

4. A condensing lens, mounted.

5. A prism for dispersion. A bisulphide of carbon prism is best, and is as cheap as any other.

6. A prism for total reflection. It can be used also for §§ 196 and 252.

7. A mirror, for § 197. It can be used with adjustable stand (No. 3).

8. Painted disk, for § 208.

9. Apparatus for Newton's rings, § 211.

10. Two double-refracting prisms.

11. A zoetrope, § 224.

12. A stereoscope, § 232.

13. A concave mirror.

HEAT. — 1. Iodine cell, for cutting off luminous radiations.

2. A differential thermometer.

3. A pair of tin plates and a copper ball, for § 257.

4. A tin and a copper ball, for specific heat, § 263.

5. Compound bar, for § 267.

6. A hygrodeik.

ELECTRICITY. — 1. Bar and horseshoe magnets.

2. Small horizontal and dipping needles.

3. Voltaic pair (Figure 172).

4. Five Bunsen's cells.

5. Astatic galvanometer.

6. Lifting-coil (Figure 181).

7. Electro-magnet (Figure 180).

8. Page's rotating apparatus (Figure 182).

9. Model of electro-magnetic telegraph (Figure 185).

10. Relay magnet (Figure 186).

11. Decomposing cell, § 327.

12. Thermo-electric pair.

13. Induction coil (Figure 188).

14. Electrical machine (12-inch plate).

15. Insulated conductor, for § 346.

16. Leyden jar.

17. Jointed discharger, § 348.

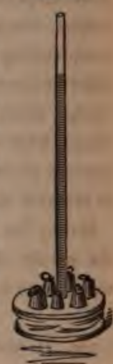
18. Electric wheel.

NOTES.

☞ These notes are numbered to correspond with the sections to which they refer.

58. The principle explained in this section is illustrated by the *hydrostatic bellows*, shown in Figure 213. It consists of two boards connected by a band of leather, forming a closed vessel, and a tube is inserted in the top or at the side. Weights are placed on this board, and water is poured into the tube. As the water fills the tube, the board rises with the weights upon it. If the surface of the board is 100 times as large as the end of the tube, one pound of water in the tube will balance 100 pounds on the board. As the surface of the board is 100 times as large as the end of the tube, there are 100 times as many particles of water in contact with the board as there are at the end of the tube; and as each particle is made to exert the same pressure, one pound of water in the tube ought to balance 100 pounds on the board.

Fig. 213.



168. Other examples of the effect of sympathetic vibrations might be given. If two clocks, for example, with pendulums of the same period of vibration, be placed against the same wall, and if one of the clocks be set going and the other not, the ticks of the moving clock, transmitted through the wall, will start its neighbor. The pendulum, moved by a single tick, swings through a very small arc, but it returns to the limit of its swing just in time to receive another impulse. In this way, the impulses add themselves together so as finally to set the clock going. It is by this timing of impulses that a properly pitched voice can cause a glass to ring, and that the sound of an organ can break a particular window-pane.

187. For a fuller account of sounding and sensitive flames, see the larger *Natural Philosophy*, Part II., pages 74–79, and Appendix, pages 373–377.

191. *The limits of hearing are different in different persons.* Dr. Wollaston, to whom we owe the first proof of this, found that one of his friends could not hear the sound of a small organ-pipe, which was not too sharp to be audible to most persons. The ascent of a single note is sometimes sufficient to produce the change from sound to silence. "Nothing can be more surprising," writes Sir John Herschel, in reference to this subject, "than to see two persons, neither of them deaf, the one complaining of the penetrating shrillness of a sound, while the other maintains there is no sound at all." Professor Tyndall relates, that, while crossing the Wengern Alp, he found that a friend, who was with him, could not hear the shrill music of the swarms of insects in the grass on the sides of the path, though to himself the sound seemed to rend the air.

It may be remarked that the shrill notes of many insects are the result of the rapid vibrations of their wings, amounting sometimes to more than 16,000 in a second.

199. In the same way, light is refracted in passing through the air, and since the air is more and more dense as it is nearer the earth, a ray of light is bent more and more as it approaches the earth. Hence we see the sun and the stars before they rise and after they set. It will be evident from Figure 214 why it is that we always see a heavenly body higher up than it really is.

Fig. 214.

Refraction varies with the condition of the atmosphere. Sometimes at sea it is so great that objects below the horizon, as ships and islands, are lifted up enough to become visible. Occasionally we have this extraordinary effect of refraction combined with mirage, so that a ship which is

really below the horizon may be seen suspended in the air with its inverted image beneath it.

200. Total reflection in a liquid may be illustrated by a simple but very beautiful experiment. Near the bottom of a tall vessel a round hole is made for water to run out; opposite this hole is a glass plate, through which a beam of solar or other light is admitted. The vessel is filled with water, and the outlet opened. The beam of light is totally reflected from the inner surfaces of the liquid jet, and is therefore carried down with it, lighting it up throughout its whole extent. For the best effect, the vessel should be set high enough to give a jet of considerable length.

209. For a brief account of *spectrum analysis*, see our *Handbook of the Stars*, pages 87–90. The subject is also discussed in the *Natural Philosophy*, Part II., pages 112–115. Teachers who are interested in the subject can get an excellent spectroscope from Alvan Clark & Sons, of Cambridge, for $35.

212. The simplest and most satisfactory way of seeing diffraction fringes is to place wire gauze of various coarseness over the object-glass of an ordinary telescope, and then to look at some brilliant point of light, as a star, or the image of the sun reflected from a flask filled with water. The fringes will vary with the coarseness of the gauze used. They may be seen even when the meshes are a quarter of an inch across. The experiment is very easy, and is well worth trying.

230. The celebrated "Spectre of the Brocken," seen among the Hartz mountains, is a good illustration of the effect of indistinctness upon the apparent size of an object. On a certain ridge, just at sunrise, a gigantic figure of a man had often been seen walking, and extraordinary stories were told of him. About the year 1800, a French philosopher and a friend went to watch the spectre. For many mornings they looked for it in vain. At last, however, the monster was seen, but he was not alone. He had a companion, and, singularly enough, the pair

aped all the motions and attitudes of the two observers. In fact, the spectres were merely the shadows of the observers upon the morning fog which hovered over the valley between the ridges; and because the shadows, though near, were very faint, the figures seemed to be distant, and like gigantic men walking on the opposite ridge.

237. The object-glass of the great telescope in the Observatory at Cambridge, Mass., is 15 inches in diameter. The telescope in the Observatory at Chicago, Ill., has an object-glass 18 inches in diameter. Such an instrument takes in as much light as the eye would if its pupil were 18 inches in diameter; that is, since the pupil of the eye is not more than a quarter of an inch in diameter $(4 \times 18)^2$, or 1,296 times as much light.

241. For an account of multiple reflections in plane mirrors and of the *kaleidoscope*, see *Natural Philosophy*, Part II., pages 177, 178.

251. The *platinum lamp* shown in Figure 215 is convenient for this experiment. *s* is a spiral of platinum wire within a glass globe; *d* is an opening in the side of the globe through which the heat from the spiral is radiated; *a* is a concave mirror for collecting and condensing the heat. The platinum spiral is connected with a galvanic battery, by means of which we can heat the wire to any desired temperature.

Fig. 215.

257. Many familiar illustrations of the fact that good absorbers are good radiators, and *vice versa* might be given. Put equal quantities of boiling water into two teakettles, one of which is polished and the other rough, and the former will cool more slowly than the latter. Put the same kettles full of cold water before an open fire, and the rough one will become hot sooner than the other.

Dark colors absorb and radiate heat better than light ones. The former are therefore the better for winter clothing, and the latter for summer. For a similar reason, snow melts very slowly even under the direct rays of the sun; but a piece of black cloth laid upon the snow causes it to melt quite rapidly.

Since a stove is meant to *radiate* heat, it is better that its surface should be rough than that it should be polished. On the other hand, a tea-urn, or any vessel intended to keep its contents hot as long as possible, should be polished rather than rough.

259. The following Table of conductivity is from Tyndall:—

Name of Substance.	Conductivity.	
	For Electricity.	For Heat.
Silver . . .	100	100
Copper . . .	73	74
Gold	59	53
Brass . . .	22	24
Tin	23	15
Iron	13	12
Lead	11	9
Platinum . .	10	8
German silver.	6	6
Bismuth . .	2	2

Examples of very bad conductors are stones, glass, wood, and animal and vegetable tissues. Artillerymen transport red-hot cannon-balls in wooden wheelbarrows partly filled with sand. Ice is preserved in sawdust. We make our garments of substances which have served to cover animals or vegetables. Woollen stuffs are warmer than cotton, because they are poorer conductors.

260. Some have denied that water conducts heat at all; but it has been proved to have a very feeble conducting power. This may be illustrated by holding the upper part of a test-tube full of water over the flame of a lamp. The water will boil before the lower end of the tube is even warm. If we put a piece of ice in the bottom of the tube, the water may even be boiled without melting the ice.

276. A still lower temperature, of —220°, has been obtained by placing a mixture of liquid nitrous oxide and bisulphide of carbon in an exhausted receiver.

Water may be readily frozen by the evaporation of ether. Put the water in a small test-tube; and place the test-tube, surrounded with cotton moistened with ether, in a wine-glass or tumbler. Put the nozzle of a bellows into the cotton, and blow vigorously. The current of air passing over the cotton acts on a very large surface of ether, which is thus evaporated fast enough to freeze the water in the tube.

277. The force exerted in the expansion and contraction of bodies is very great. A curious application of this force was made by the architect Molard, at the *Conservatoire des Arts et Métiers*, in Paris. The walls of a vaulted gallery in this building had been pushed outward by the weight of the stone roof, and it was feared that the whole would fall. Molard put iron bars across the gallery through the walls, the ends of the bars having a screw-thread fitted with nuts. He then heated the bars throughout their whole length, screwed them up tight, and allowed them to cool. The gradual contraction of the iron drew the walls nearer together without injuring them. The process was repeated several times, until the walls were restored to a vertical position. The bars were left to keep them in place, and may be seen to this day.

Advantage is taken of the force of contraction in putting tires on wheels. The tire is put on hot, when it fits loosely; but as it cools it contracts, and grasps the wheel with very great force.

For other illustrations of the kind, see § 295.

287. The vapor in the atmosphere acts in the same way as the glass of the hot-house: the luminous rays from the sun easily penetrate it, and fall upon the earth; but they cannot make their way back through it when radiated from the earth as obscure heat. See the chapter on the *Physics of the Atmosphere*, § 2.

Saussure made a wooden box, blackened within, having one of its sides formed of three panes of glass, separated by thin

layers of air. He then put a vessel of water in the box, and exposed the glass side to the rays of the sun; and in this way he succeeded in making the water boil. The luminous heat easily passed in through the glass and the air, and was absorbed by the blackened surface; but when radiated back as obscure heat, it could not escape from the box, and after a time it had accumulated sufficiently to boil the water.

307. The zinc used for battery purposes should, in all cases, be amalgamated. Full directions for the process are given in the *Natural Philosophy*, page 379.

312. To make a simple rheotome and rheotrope, fill two small cups with mercury, and put the ends of the battery wires into them. Put the end of another wire into each cup, and use these latter wires to convey the current where you wish to use it. The current can be instantly broken by taking one of these wires out of the mercury; and the direction of the current can be changed by shifting the wires from one cup to the other.

For a description of Foucault's self-acting rheotome, see *Natural Philosophy*, Part II., page 301.

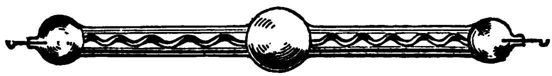
333. Various arrangements have been invented for giving steadiness to the electric light by keeping the carbon points within such a distance of each other that the current can pass between them. Foucault, aided by Duboscq, was the first (in 1849) to construct an electric lamp of this kind. In it, by means of an electro-magnet and of clock-work, the points are made to travel towards each other at rates corresponding to those of their combustion, the positive pole moving faster than the negative.

The electric lamp has not yet been used successfully for lighting streets. The light may be kept up for hours, but even then it is not perfectly steady, and the apparatus cannot be safely left without an attendant. It has, however, been used with excellent effect where a limited space had to be lighted for a few nights, as in building bridges. It has also been used with success for light-

houses, in England and France. The power of the electric light to penetrate fogs is found to be far superior to that of the usual oil light.

When the induced current is made to pass through highly rarefied air, a very beautiful effect is produced. This may be shown by *Geissler's tubes* (so called from the inventor), which are combinations of bulbs and tubes, filled with rarefied gases and liquids, and then sealed air-tight, so as to be ready for use at any time. One of them is represented in Figure 216. When

Fig. 216.



the current is sent through these tubes, they exhibit lights of various tints according to the gases contained in them.

A very pleasing illustration of the electric light in rarefied air is afforded by the "guinea and feather tube," shown in Figure 50. If the ends of the tube are connected with the poles of the inductorium, or with the electrical machine, purple flashes of auroral light mark the passage of the current through the tube when the air is exhausted. In all experiments of this kind, the room should be darkened.

Gassiot's cascade is a simple and inexpensive piece of apparatus for showing the electric light in a vacuum. It consists of a large glass goblet (uranium glass is best), the inside of which is coated nearly to the top with tinfoil. Place the vessel on the plate of the air-pump, cover it with a receiver which has a sliding rod through the top, bring the sliding rod in contact with the tinfoil coating, and connect one pole of the inductorium (or one conductor of the electrical machine) with the rod, and the other with the pump-plate. When the air is exhausted, and the current sent through the receiver, streams of blue light flow from the tinfoil over the side of the vessel to the pump-plate. A variety of beautiful effects are produced by different degrees of exhaustion, and by changing the direction of the current.

The apparatus known as the *Abbé Nollet's Globe* also furnishes very pretty displays of the electric light in rarefied air. It consists of a glass globe suspended in the upper part of a glass bell-jar, and arranged so that it can be partially filled with water, and then connected with the inductorium or the electrical machine by a chain dipping into the water. The light in this case flows in lambent streams from the globe to the pump-plate.

A variety of pieces of apparatus for showing the electric light are made by pasting bits of tinfoil about $\frac{1}{20}$ of an inch apart on glass, oiled silk, or other non-conducting substance. Letters, outline figures, etc., may thus be formed, which appear in lines of scintillating light when the current is sent through them.

The pieces of tinfoil may be pasted in a spiral on the inside of a long glass tube, and lighted up in the same way.

The *diamond jar*, as it is sometimes called, is a Leyden jar, the coatings of which are composed of small pieces of tinfoil, separated from one another. Brilliant sparks pass between these pieces when the jar is charged or discharged.

337. A Ruhmkorff's coil of moderate size readily yields sparks of from four to five inches, with a battery of six Bunsen's cells. The power of the induced current to turn a needle, and to effect electrolysis, is very slight. This shows that it is very much *inferior to the inducing current in quantity*, though *much superior in tension*. The *physiological* effect is very powerful, and care must be taken not to allow any part of the body to form the connection between the poles, as the shock might be dangerous, if not fatal.

347. When an insulated conductor is brought near a charged body, it is first *polarized;* and the nearer it is brought, the higher the polarization rises. If the conductor discharges its force at the end nearest the polarizing body, it becomes *charged* with the same electric force as the polarizing body; if it discharges from the opposite end, it becomes charged with the force opposite to that on the polarizing body. If the conductor can discharge quite readily at both ends, but more readily at one end

than at the other, there will be three steps in the process. It will first become *polarized*, then *charged*, and finally *neutralized*.

If the conductor can discharge quite readily, and with equal readiness at each end, there will be only two steps in the process: it will be first *polarized*, and then *neutralized*.

PHOTOGRAPHY.

1. *The Daguerreotype.*—If the image in the camera obscura (218) be allowed to fall for a short time upon a copper plate coated with argentic iodide (iodide of silver), and the plate be removed and examined, no change appears to have taken place. If, however, the plate be now exposed to the vapor of mercury, an image appears exactly like that formed in the camera. The mercury condenses upon those parts of the plate which have been most strongly illumined, and thus *develops* the picture which before was *latent*. If this plate were now exposed to the light, the remaining iodide would blacken so as to obliterate the picture. But if the iodide be dissolved and washed off by a solution of sodic hyposulphite (hyposulphite of soda), the picture is fixed. This process of obtaining pictures by means of light was discovered in 1839 by a Frenchman named Daguerre, and from him the pictures are called *daguerreotypes*.

For the *theory* of the daguerreotype process, see *Natural Philosophy*, Part II., page 183.

2. *The Collodion Process.*—This process, which is the one now almost universally employed, was invented by Mr. Archer, in 1851. A solution of gun-cotton in a mixture of alcohol and ether is impregnated with a small quantity of potassic or of cadmic iodide (iodide of potassium or cadmium), forming what is called *iodized collodion*. A film of this is spread on a plate of glass, which is then immersed in a solution of argentic nitrate (nitrate of silver). The collodion film thus becomes coated with yellow argentic iodide (iodide of silver), which is very sensitive to light. The plate thus prepared requires an exposure of only a few seconds in the camera to produce the *latent image*, which is afterwards developed by pouring over the surface a weak

solution of pyrogallic acid mixed with acetic acid. A solution of ferrous sulphate is also often used for the same purpose. The image is now *fixed*, as described above, by pouring over the plate a solution of sodic hyposulphite, or of potassic cyanide (cyanide of potassium). The *negative* picture thus obtained can then be employed for printing a *positive*, as explained in the next section.

3. *Photographic Printing.*—In 1839, Mr. Fox Talbot, of England, discovered the process now known as *photographic printing*. It consisted in soaking ordinary writing-paper in a weak solution of common salt, and, when dry, washing it over upon one side with a solution of argentic nitrate (nitrate of silver), consisting of one part of a saturated solution of nitrate with 6 or 8 parts of water. This operation was performed by candle-light, and the paper was dried at the fire; in this manner a film of argentic chloride, mixed with an excess of argentic nitrate, was formed upon the surface of the paper. Suppose that it were desired to obtain a copy of an engraving, or of the leaf of a tree: one of the sheets so prepared was laid under the engraving or the leaf which was to be copied; the two were pressed firmly together between two plates of glass, and exposed to the direct rays of the sun, or even to diffused daylight, for half an hour or an hour. The impression thus obtained was a *negative* one; that is to say, the shadows were represented by lights, and the lights by shadows; those portions of the surface which had been exposed to the strongest light becoming dark, and the parts corresponding to the deep shadows in the engraving remaining white. The pictures were then fixed by immersing them in a strong solution of common salt. Considerable improvements have been introduced into this process since it was first published; but, in principle, this operation, which has been termed *photographic* printing, remains unchanged.

Of course, when *negative* pictures are copied by this process, *positive* ones (or those having the proper distribution of light and shade) are obtained.

QUESTIONS FOR REVIEW AND EXAMINATION.

☞ *The numbers refer to the sections of the book.*

COHESION. — 1. Show that bodies are made up of molecules. What are molecules? 2. Show that molecules are very small. 3. State the effect of cold upon solids, liquids, and gases. What follows from this? 4. What is true of the spaces between molecules? 5. What forces act between molecules? Prove this. 6. Show that these forces act together. 7. Define the three states of matter. 8. What is cohesion? adhesion? 9. Through what distances do these forces act? Prove this. 10. What is true of cohesion in solids? 11. Define tenacity. Describe the dynamometer, and explain its use. 12. When is a solid hard? When soft? What is the test of hardness? 13. Define and illustrate elasticity. What is meant by the limit of elasticity? When is a body brittle? When malleable? When ductile? How is gold-leaf made? Wire? What facts about iron wire? 14. Show that solids are compressible. 15. What are crystals? How may we get crystals of alum? of sulphur? In order to crystallize, in what state must the substance be? Why? How are large crystals obtained? Explain the formation of crystals in iron axles, etc. What is said of ice? 16. What is true of the different sides of molecules? Prove this. 17. Describe Rupert's drops. Explain annealing and tempering. 18. What is true of cohesion in liquids? Of the spaces between the molecules in liquids? 19. Are liquids compressible? How may this be proved? 20. Are liquids elastic? Show this. 21. How do the molecules of liquids tend to arrange themselves? Give illustrations. 22. What is said of cohesion in gases? Of the molecules of gases? 23. What of the compressibility of gases? 24. What of their elasticity? Recite the Summary of Cohesion.

ADHESION. — 25. Give illustrations of adhesion between solids. What is sometimes true of this adhesion? 26. What is said of adhesion between solids and liquids? 27. Describe the experiment with balance and glass disk. What does it show? 28. What is shown by the experiment with a glass plate laid on water? What is the effect of pulverizing a solid? Why? Explain the clarifying of liquids. 29. What is shown by the experiment with Epsom salts? 30. State the three cases of adhesion between solids and liquids. 31. How does heat affect solution? Why? 32. What is capillarity? The origin of the word? State the different cases of capillarity. 33. Give illustrations of capillarity. 34. Show the strength of capillarity. 35. Will a liquid overflow a capillary tube? Show this. Explain the burning of a common lamp. Why must an alcohol lamp have a cap? 36. Describe the experiment with ammonia and charcoal. What does it show? Why is the charcoal first heated? 37. Give the facts concerning the adhesion of liquids to liquids. 38. What is the diffusion of liquids? Illustrate by experiment. 39. Describe and illustrate osmose of liquids. 40. What experiment shows the adhesion of liquids and gases? 41. Illustrate the effect of cold and of pressure on this kind of absorption. What is said of aqua ammonia? of spring-water? 42. Describe and illustrate diffusion of gases. 43. What is osmose of gases? Illustrate. Recite the Summary in full.

PRESSURE. — 44. What is gravity? What law of gravity is mentioned? 45. What is weight? 46. Describe the spring balance. 47. Describe the balance. 48. The steelyard. 49. Define centre of gravity. 50. What is sometimes true of the position of this centre? Illustrate. 51. Define equilibrium. Its kinds? 52. Show that the centre of gravity seeks the lowest point. On what does stability of equilibrium depend? Prove this. What does the experiment with the cork balanced on a needle show? What other illustrations of the same kind? 53. How do we find the centre of gravity of a solid? 54. How is the weight of a liquid found? 55. How do liquids press when acted on by gravity? 56. What is true of the pressure while the depth of the liquid remains the same? Prove this. 57. At varying

depths, what is true of the pressures? Prove this. 58. Explain the effect of additional pressure exerted on any particle of a liquid in a closed vessel. 59. Describe the hydrostatic press. Explain its working. Its uses? 60. What is said of springs? Of Artesian wells? 61. Show that a body is buoyed up by a liquid. 62. How much is it thus buoyed up? Prove this. When will a body float in a liquid? How can iron be made to float on water? 63. What is true of the density of bodies? What is the specific gravity of a body? 64. How do we find the specific gravity of solids? 65. Describe the two forms of hydrometer. Their use? Give other ways of finding the specific gravity of liquids. 66. Prove that gases have weight. 67. What is true of the pressure of gases? Show this by experiments. 68. Show that gases have an expansive force. 69. Describe the air-pump, and explain its action? 70. Prove that bodies are buoyed up in air. How much? 71. Why do balloons rise? How are they made? 72. Show that the pressure of the air will sustain a column of liquid in an inverted vessel. 73. How high a column of mercury will it sustain? 74. How much is the pressure of the air on a square inch? Show this. 75. Is the pressure always the same? 76. How is the pressure affected by the height of the place? 77. What is a barometer? Describe the form given here. 78. What are the uses of the barometer? 79. Describe and explain the lifting-pump. The different forms of force pump. The fire-engine. 80. What is a siphon? Explain its action. 81. Describe Tantalus's cup. What is said of certain springs? 82. What does the air-gun illustrate? Describe it. Explain the action of gunpowder on a bullet. Describe the condenser. 83. State Mariotte's law. Why is it so called? 84. Describe the spirit level.

MOTION.—85. Define inertia. 86. What is the first law of motion? 87. What is necessary to make a body move, or to change the rate of its motion? Show this to be so. 88. What is the effect of a force acting for a moment? 89. Of a force acting continuously? 90. What is true of the resistance a moving body meets? 91. When is a moving body in equilibrium? Illustrate. 92. What is the second law of motion? Illustrate it.

93. When does a body move in a straight line? a curved line? 94. How does gravity tend to make all bodies fall? Prove this by an experiment. 95. How does gravity affect the velocity of a body moving downward? 96. How far will a body fall in a given time? 97. What is the effect of gravity on a body moving upward? 98. How high will such a body rise in a given time? 99. Define mass and momentum. 100. What is the third law of motion? What is it often called? Give illustrations of the law. 101. Show that it takes time to give motion to a body as a whole. On what does the piercing power of a projectile depend? 102. What is reflected motion? Its law? 103. What is a pendulum? 104. What is the first law of the pendulum? Explain the word isochronism. 105. The second law of the pendulum? 106. The third law? 107. The fourth law? 108. The chief use of the pendulum? What is a clock? Describe its parts, and their working.

MACHINES. — 109. What is a lever? The weight? The power? The fulcrum? The arms of the lever? The three kinds? 110. What is the law of the lever? Illustrate. 111. The general law of machines? When does there seem to be a gain of power in a machine? When a loss of power? 112. Explain the gain and loss of power in the three kinds of lever. 113. Describe and explain the compound lever. 114. What is said of bent levers? 115. Describe the rack and pinion. 116. Of what is it a modification? Show this. 117. Describe the windlass. 118. The capstan. 119. The wheel and axle. Show the application of the general law to this machine. 120. Describe the ratchet. Its use? 121. What is wheel-work? Why used? Describe the different kinds of wheels. How are they made to act on one another? 122. For what is the pulley used? 123. Define fixed and movable pulleys. 124. The law of the pulley? 125. Show the application of the law of machines to systems of pulleys with one rope. 126. Describe systems with more than one rope. 127. What is an inclined plane? 128. The law of the inclined plane? 129. What is a wedge? Its law? 130. Its uses? 131. What is a screw? Its parts? 132. Describe the endless screw. 133. What kinds of water-wheels? 134. Describe the breast

. The overshot wheel. The undershot wheel. 135. ibe Barker's mill. Explain its action. 136. What is said : turbine? 137. Show how steam may be made to move :on. What is reciprocating motion? How changed to r motion? Describe the engine in Figure 86. 138. De- the governor. Its use? 139. What is the fly-wheel? Its 140. What is a high-pressure engine? A low-pressure e? 141. The purpose of the boiler? Its construction? ibe the Cornish boiler. The locomotive boiler. 142. De- the other parts of the locomotive.

ND. — 143. Show that a sounding body vibrates. 144. that sound does not pass in a vacuum. 145. Show that sses through all gases. 146. Does sound pass through s? Solids? Prove this. How is sound produced? 147. hat does its intensity depend? Show this. 148. The law : intensity of sound for different distances? 149. Explain ing-tubes. 150. The velocity of sound in air? How found? ts velocity in water? When and how found? 152. Its ty in solids? 153. When is sound reflected? The law of flection? 154. What are echoes? Mention some remark- :choes? 155. What is noise? musical sound? Describe ment. 156. On what does the pitch of musical sounds d? 157. Describe the tuning-fork. 158. Describe the 159. Its use? 160. What is an octave? 161. Describe nometer. Its use? 162. On what does the rapidity of the ion of a string depend? 163. What are notes? Give ex- ents illustrating their formation in strings. 164. How may be formed in plates? What are nodal lines? 165. What rertones? 166. What is quality in sound? Illustrate. how the transmission of musical sounds through liquids olids. 168. What are sympathetic vibrations? Illustrate. llustrate the interference of sounds. 170. When are beats ced? 171. What is unison? A fifth? A fourth? Are they y pleasing to the ear? What is a major third? A minor A chord? A discord? 172. What are stringed instru- ? 173. What is the use of sounding-boards? 174–177. the laws of the vibration of strings. What two classes

of stringed instruments? 178. What is said of longitu vibrations in rods free at one end? 179. In rods free at b ends? 180. Give experiment illustrating resonance? 181. H may a column of air in a tube be made to vibrate? 182. what rate does such a column vibrate? 183. What is true of vibration in open and in stopped tubes? 184. What are org pipes? Explain their action. 185. What is a reed? How it produce sound? 186. What two classes of wind instrume 187. Show that friction is always rhythmic. How may the of a flame be changed to music? 188. What is said of sen flames within tubes? 189. Describe the organ of voice in How may its action be illustrated? 190. Describe the h ear? 191. What is the range of human hearing?

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E.

F.

G.

H.

I.

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APPARATUS.

The following articles named in the List on pages 295–299 can be furnished at the prices affixed: —

COHESION.

1,	Ring and ball	$2.25
2,		1.25
3,		1.00
4,		1.75
5,		.25
6,		.75
7,		3.00
8,		.38
9,		.75
10,		3.00
11,		5.00
12.	The price varies, but averages (per lb.)	1.25

ADHESION.

1,		$13.00 or 25.00
2,		1.50
3,		1.00
4,		2.00
5,	2 cylinders; one, 1 inch in diameter and 6½ inches deep; the other, 1½ in diameter and 7½ deep, with covers	50
		.25
6,		.50
7,		

8,	. . . .	$1.00
9,	. . . .	1.00
10.	Hunt's improved hydrogen generator	5.00

MECHANICS.

1,	. . . .	3.00
2,	. . . .	5.00
3,	. . . .	6.00
4,	. . . .	25.00
5,	. . . .	7.00
6,	. . . .	1.25
7,	. . . .	45.00
8,	. . . .	8.00
9,	. . . .	1.25
10,	. . . .	11.00
12,	. . . .	1.00
13,	. . . .	22.00
14,	. . . .	.50
15,	. . . .	1.75
16,	. . . .	8.00
17,	. . . .	8.00
18,	. . . .	3.50
19,	. . . .	8.00
20,	. . . .	2.00
21.	. . . .	25.00

SOUND.

1,	. . . .	3.00
2,	. . . .	12.00
[illegible],	. . . .	27.00
	Sonometer, with strings and weights, complete . .	25.00
Tant[illegible] Teleg.	. . . .	5.00
	. . . .	2.00
	. . . .	.75

C

8,	$8.00
9,	1.50
10,	2.00
11,	6.75
12,	2.50
13.	1.00

LIGHT.

2,		30.00
3,		5.00
4,		7.00
5,		12.00
6,		12.00
7,		1.00
8,	Apparatus complete	13.50
9,		10.00
11,		10.00
12,		$3.00 to 5.00
13.	Two mirrors; one convex and one concave	5.50

HEAT.

1,	6.00
2,	3.50
3,	3.00
4,	2.00
5,	1.50
6.	15.00

ELECTRICITY.

1,	2.50
2,	4.50
3,	1.50
4,	22.00
5,	12.00

6.	. . . .	$4.00
7,	. . . .	8.00
8,	. . . .	7.00
9,	. . . .	7.00
10,	. . . .	15.00
11,	. . . .	4.00
12.	. . . .	2.00
13,	. . . .	16.00
14,	Electrical machine (16-inch plate)	32.00
15,	. . . .	15.00
16,	. . . .	2.00
17,	. . . .	5.00
18.	. . . .	$2.50 or 4.50

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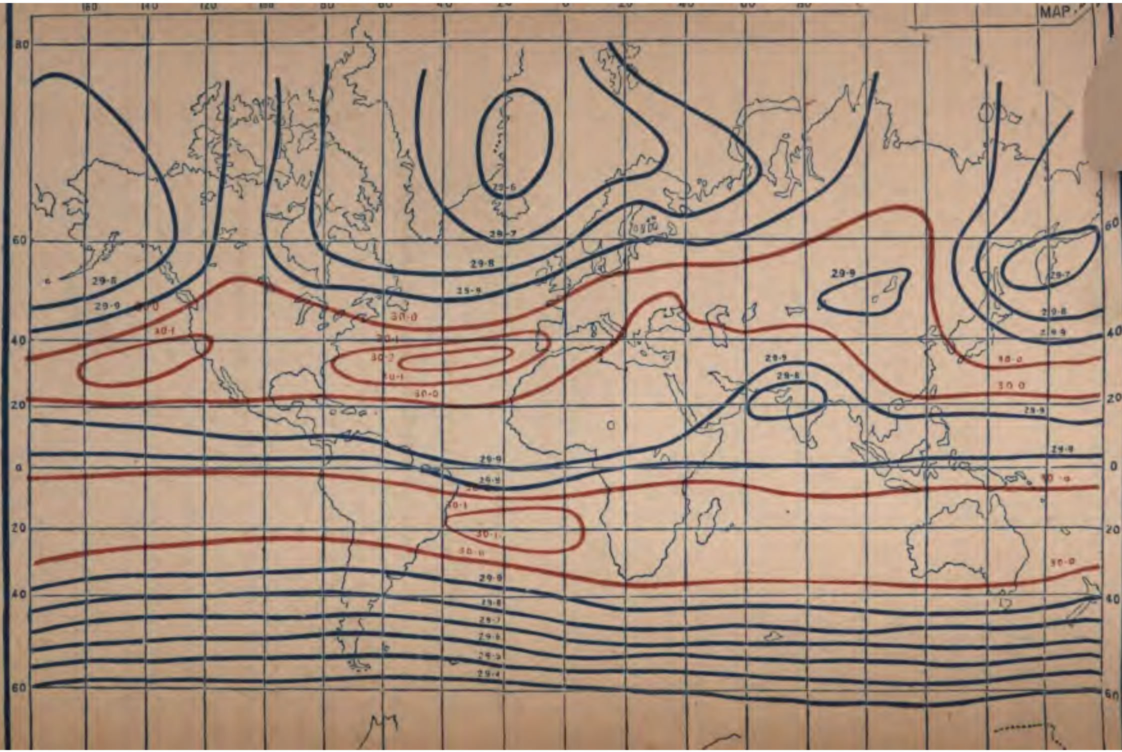

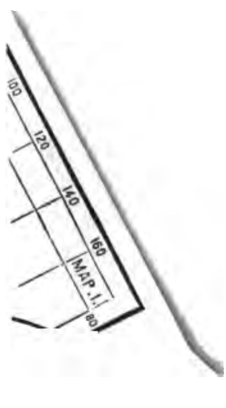
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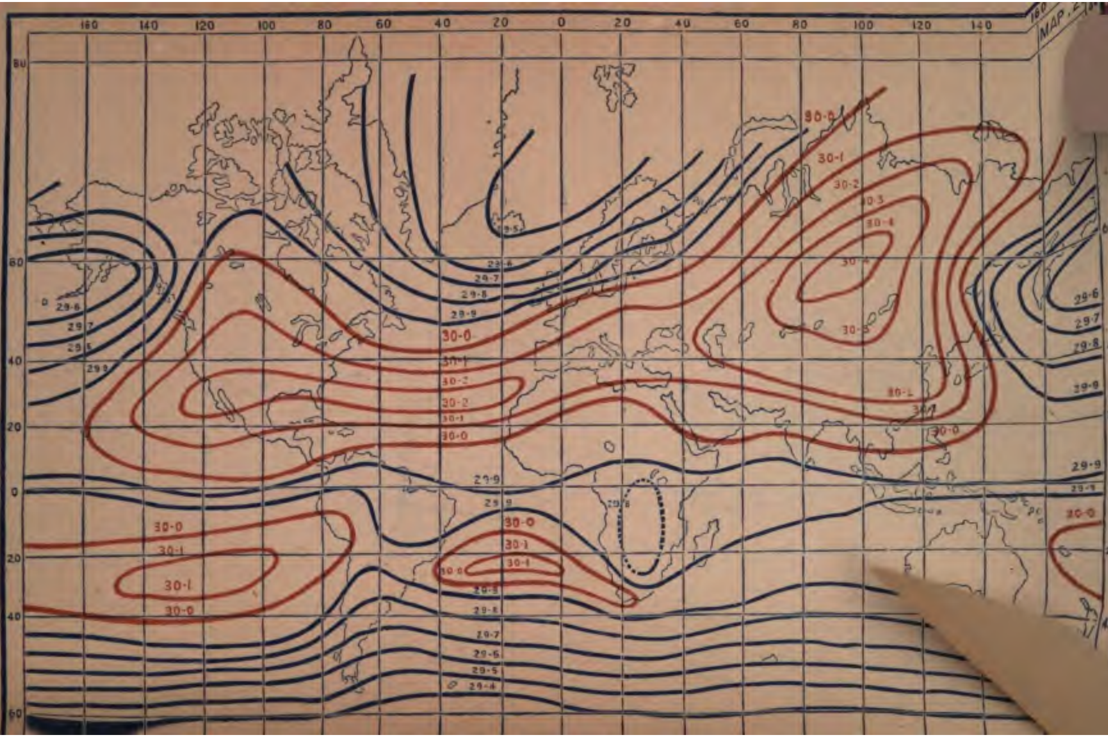

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